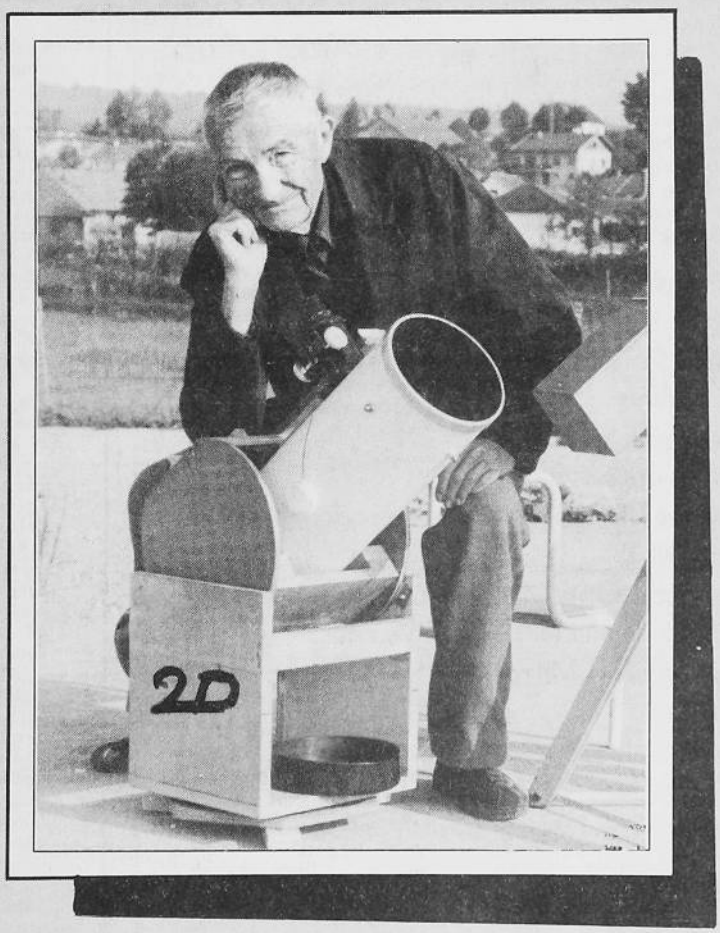
TELESCOPE MAKING 14

ISSN 0190-5570

The magazine *for*, *by*, and *about* telescope makers!

Winter 81/82



an issue in honor of Adrien Poncet

TELESCOPE MAKING

The magazine *for, by* and *about* telescope makers!

Editor: Richard Berry

Associate Editor: Robert E. Cox

Managing Editor: Katherine M. King

TELESCOPE MAKING (ISSN 0190-5570) is published quarterly by AstroMedia Corp., P.O. Box 92788, Milwaukee WI 53202. Copyright © 1982 by AstroMedia Corp., all rights reserved. No part of this issue may be reproduced by any mechanical, photographic or electronic process or otherwise copied for public or private use without written permission of the publisher. The opinions expressed in this magazine are not necessarily those of the publisher or editors. POSTMASTER: When undeliverable, send form 3579 to publisher. Direct all inquiries, complaints, editorial submissions, and other correspondence to: TELESCOPE MAKING, P.O. Box 92788, Milwaukee, WI 53202; telephone (414) 276-2689. Not responsible for unsolicited materials. Names and addresses of authors will be printed unless specifically requested otherwise. Subscription price (U.S.): 1 year $10.00; single issues $2.50; other countries: 1 year $12.00, single issues $3.00. Clubs and dealers: Inquire about bulk rates. Copy Editor: Ross Parker Simons; Typing: Mary Algozin & Debbie Weinstein; Art Assistants: Jane Borth and Mary MacAdam; Advertising: Mary Kuklinski. Printed by Port Publications, Port Washington, WI.

In this issue...

2 Editorial
3 Letters
4 Astrophotography with a Poncet
by Dick Houskeeper
10 A Four-Axis Poncet Mount
by Steve Dodson
16 Dual Axis Equatorial Platforms
by Richard Berry
17 A Bending-Pier Telescope Mount
by Graeme White
18 Nine Telescope Optical Systems Compared
by H.G.J. Rutten and M.A.M. van Venrooij
24 Pyrex Honeycomb Mirrors
by John Hill and J.R.P. Angel
28 Commercial Telescopes
by Kevin Ritschel
32 A 20″ Thin-Mirror Dobsonian
by Richard Wessling
36 Designing Maksutov Telescopes from Scratch
by Bill Sutherland
44 The Blue Pages Classified

Editorial

Telescope making is changing as much for us, the amateurs, as it is for professional astronomers and for the commercial manufacturers. Look at what happened in the last ten years — the introduction of the Dobsonian, the Poncet, inexpensive commercial mirrors (which virtually made grinding your own obsolete), several 100"+ thin-mirror infrared telescopes, multiple primaries for professional telescopes, the mass-produced amateur market Schmidt-Cass, precision eyepieces to replace the surplus stuff of the 60s -- and wonder at the changes!

Now, in your mind, roll the rate of change in the last decade plus a phenomenal growth in the popularity of astronomy in with today's sluggish economy. How will the needs of the expanding market influence the telescope makers? More low cost telescopes, like compact cars? Whatever happens, one thing is for sure: things **will** change. I'd certainly enjoy hearing your ideas, and publishing your letters on the future of amateur, professional, and commercial telescope making.

One area that's already changing is equatorial mountings. I've dedicated this issue to M. Adrien Poncet, and devoted about one-third of its pages the Poncet-type equatorial. Steve Dodson's ring mount is a breakthrough, and Dick Houskeeper's photographic Poncet shows that the equatorial table **can** do it. It's sure to inspire others, especially some with big Dobsonians.

In the commercial arena, Roger Tuthill has placed a Poncet platform on the market, and has done some pretty good guided deep sky stuff with it. Meanwhile, the 812 mount by Byers, the first really research quality amateur market mount, ought to revolutionize astrophotography. It and 2415.

Hill and Angel (see page 24) write on another critical problem: sooner or later, we've got to circumvent the price and weight of big slabs of glass. It looks like a feasible club project to

TM Subscriptions & Renewals

☐ $10 for 4 issues ☐ New subscription ☐ New Address
☐ $18 for 8 issues ☐ Renewal

Name _____

Address _____

City _____ State _____ Zip _____

Your subscription will begin with the next issue published. Payment must accompany your order. All back issues available at $2.50 each.

When to renew: see your mailing label.
This will be your last issue.

T 053202BERRR927B0 TM16
RICHARD L BERRY
BOX 92788
MILWAUKEE WI
53202

Telescope Making/Circulation Dept./P.O. Box 92788/Milwaukee, WI 53202

make three or four 24" honeycomb blanks. And wouldn't it be nice to see less expensive blanks on the market? I'm still privately rooting for big refractors, but the cost of glass may have pushed them forever out of sight.

On a different note, the editorial and letter in TM#13 struck a sensitive nerve. First, I got letters from people who related complaints about bad experiences, and wanted their letters published. These I turned over to Mary Kuklinski, ASTRONOMY's Advertising Coordinator, since she can sometimes expedite their problems. Second, I got a letter from a lawyer saying that we're flirting with a lawsuit. Our lawyer said that is not true unless we actually name a firm. Third, I was accused of bad judgement in printing anything derogatory about a telescope manufacturer since it generates bad publicity for the telescope industry. I'm sorry, I said, but the industry has to live with its performance. There are plenty of reputable firms. They make good stuff, they deliver on time. I'm unhappy to see them hurt. But who's going to speak for the consumer....

On the constructive side, Kevin Ritschel sent an article. I had several calls from people who felt that while we're on the right track, we're not doing enough. Starting off with the most popular and widely advertised brands, they want us to do "consumer reports." Ouch! Too bad, but not now -- it's too expensive, time-consuming and difficult to do them properly. But we're looking at it down the road.

Several people phoned just to let me know how much they appreciated our taking a stand. I asked them to write -- since such letters help me convince my boss, Bob Maas, that a moderate degree of consumerism can be good for both consumers and the telescope industry.

Sincerely,

Richard Berry
Editor

Letters

South Pacific

Sir / I have been an ardent amateur astronomer for a number of years and have always hoped for a view of the southern skies. My wife and I are now serving as Peace Corps Volunteers in Fiji (latitude -18°) so that my hopes are near realization, telescopically speaking. Just before leaving the States, I bought a copy of "How to Build a Dobsonian Telescope" and also packed up all the makings of a 6" f/6 telescope — so I'm ready to go except for the required Teflon® bearings. Could you please send (airmail, please) the address of a dealer of small quantities of Teflon® to the address below? My students and I would be very grateful.

John Hurley
Box 3123
Lami, Fiji Islands
South Pacific

— I did better than that: from a small stock of Teflon® (love that trademark!) on hand, I sent enough material for several 6" telescopes. My thanks to those who have given me their scraps for such distribution.

More on Springfields

Dear Richard Berry / Well, it's been at least three months since your articles in ASTRONOMY and TELESCOPE MAKING about the Riverside Conference were published. And I'm just getting around to thanking you for the fine coverage of the event and the write-up you did on my eight-inch Springfield telescope. I surely could not have anticipated the extremely favorable response it generated both at the conference and in your articles.

Credit, of course, should go to Russell Porter for having thought up the design in the first place. It truly is a pleasure to sit comfortably in one place and observe the entire sky. Also, the use of thrust bearing surfaces instead of ball bearings and long, heavy shafts not only increases the mount's rigidity, but it also greatly reduces the weight and simplifies the construction, at least in my opinion.

As you pointed out in ASTRONOMY, we don't see Springfields very often. As a matter of fact, the only one I have actually seen besides my own was the very large 12" that was on display at the 1980 Riverside Conference. I've seen several in photographs in *S&T*'s "Gleanings," however. All have one important feature in common which might explain their comparative rarity: they aren't portable. This is understandable, of course, when one considers that when they were first conceived, the dark skies were often in one's backyard. Most of Porter's telescope ideas are permanently mounted ones, so mass in the Springfield designs was no problem. Also, Porter was fond of castings and machine work, and perhaps in those early days people had the room and the time to tackle such projects. Add to this the fact that commercially-built telescopes were no where near as abundant as they are today, plus relatively more expensive, and you end up with a greater drive for building your own instrument.

Thus it seems to me that the Springfield has been a victim of a series of unfortunate circumstances. I hope if I have accomplished anything by winning the award, it will be because I will have encouraged others to build Springfields of their own. It truly can be a portable instrument with the use of lightweight materials — such as aluminum and wood — and to hell with steel shafts. They're too heavy for use in a portable instrument, and particularly in a Newtonian, which must have a large cross-section in its mount components because of the tube's increased moment when compared with Schmidt Cassegrains.

Oh well, perhaps I'm getting carried away with my prejudices. Still, I recommend Russell Porter's unusual designs (but particularly the Springfield) as having a lot of potential for modern amateur astronomy. There's a lot of fine thinking there which should be appreciated by the builder with today's requirements (particularly portability and compactness) in mind.

Tim Parker
13763 Meyer Rd.
Whittier, CA 90605

➤ 34

ASTROPHOTOGRAPHY ON A SHOESTRING BUDGET with Dobson, Poncet, Kodak, et. al.

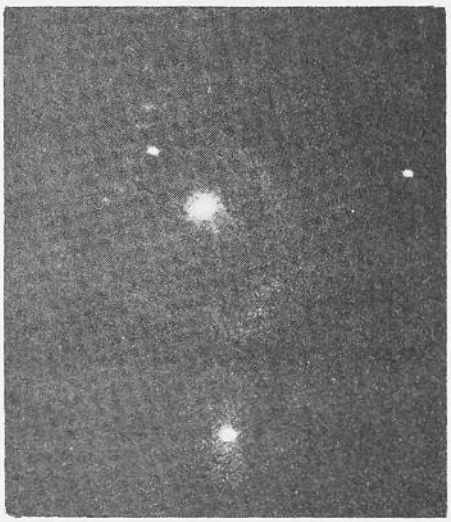
How I Got Hooked

I am a recent convert to the hobby of astronomy/telescope making. Like many people, I was lured out of the closet by the gospel according to John Dobson with the promise of relatively large, inexpensive telescopes. About a year and a half ago my son, Mark, age 10 at the time, and I assembled an 8" f/7 scope out of purchased parts and miscellaneous junk found in the desert near our home. This scope was constructed according to Dobsonian principles, although the mirror and cell were conventional. The resulting product excelled in two respects: a) ugliness, and b) quality of image. The $175 we invested in the original scope was an exceptional value and we have enjoyed it immensely.

Now a brief word of philosophy and disclaimer is appropriate here. The original scope was one of those famous "quick and dirty" projects to see how a reflecting telescope works. We intended to refine it later. After hauling it to various star parties, I found that I generally liked it the way it was. It worked well, and many newcomers and first time viewers were attracted to it because of its crude and simple appearance. "Gee," they said, "if telescopes are pretty simple, I'll bet I could make one."

At the time of construction, I hadn't decided whether I would later require tracking capability — but about the same time, I heard of the concept of an equatorial tracking table by Adrien Poncet. I assumed that I could always employ one of these devices to make an instant astrophotographic device out of my Dobsonian. Sure enough, after a few months I got the urge to take pictures.

As I read further and looked at published Poncet pictures, I discovered that the state-of-the-art was 50mm unguided exposures or short focal length, semi-guided, piggy-back exposures. The challenge became obvious: Going in stone-cold, and having zero photographic experience (let alone astrophotographic), could I turn my Dobsonian into an astrophotographic device equivalent to the commercially available, conventional stuff?



An 8 minute guided exposure on Tri-X with an 8" f/6 Newtonian on a Poncet table. Enlarged 17x.

Specifically, I wanted to take good, prime focus, deep-sky pictures through my telescope.

In the spirit of the original telescope, the project reported here was intended to be a feasibility study. As the photos show, no attempts at cosmetic improvements have been made in spite of my wife's uncharitable comments.

Mounts in General

In order to understand the Poncet mount, it is good to review equatorial mounts in general. All equatorials cause the moving pieces to rotate about an axis which is parallel to the Earth's axis of rotation. The various types (German, fork, etc.) are merely variations in the arrangement of the bearings and structure.

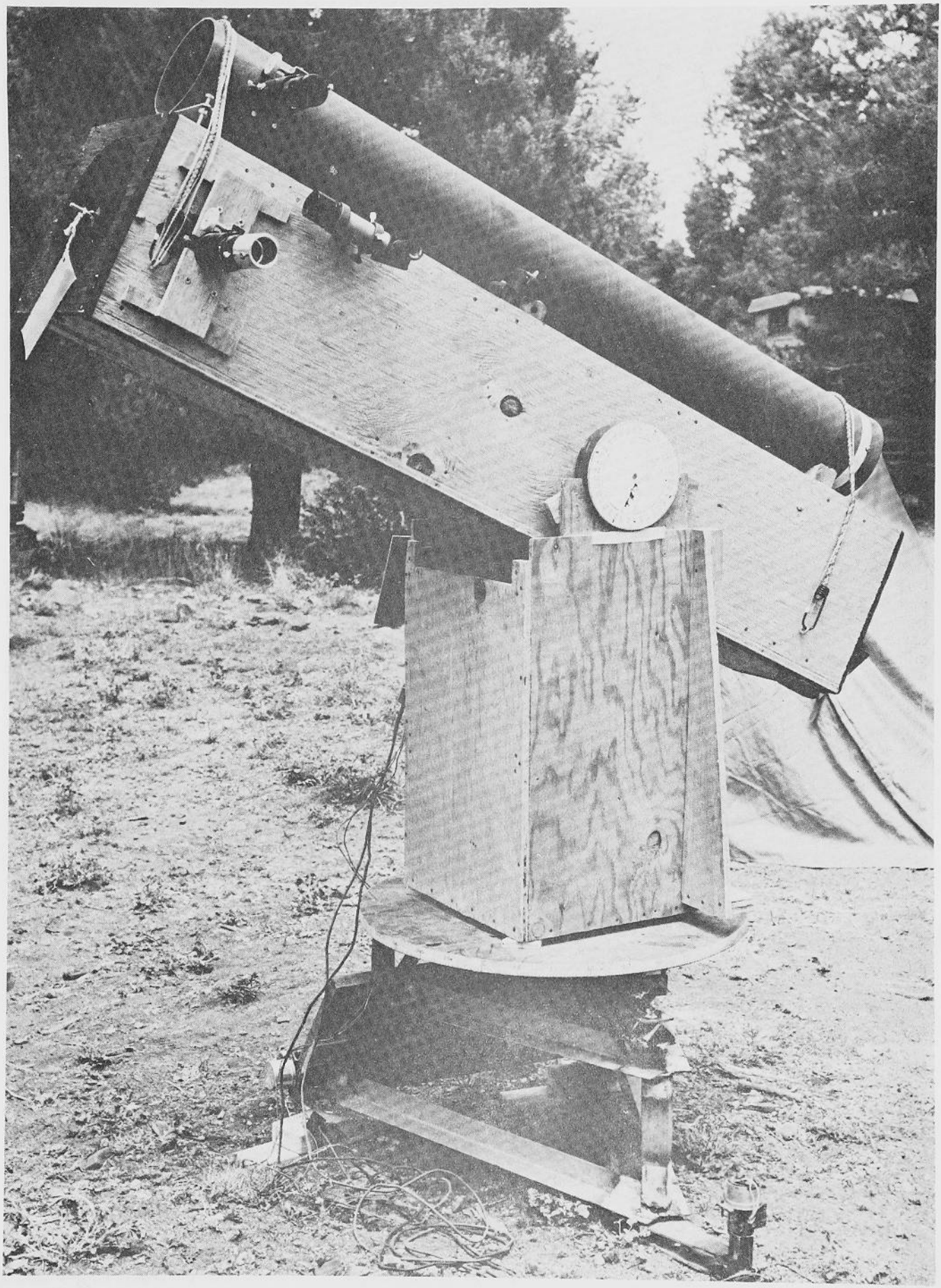
The Poncet mount is similar to the ring or horseshoe mount in that the northern bearing surface is large in diameter and offset from the axis of rotation. Instead of a horseshoe, the Poncet uses a flat plate for the north bearing to run on. Since the rotation is limited by its geometry, some extra articulation of the telescope is required for pointing, such as the altitude and azimuth bearings of the Dobsonian mount. One fringe benefit of this arrangement is that the eyepiece is always in a convenient location compared to conventional equatorials.

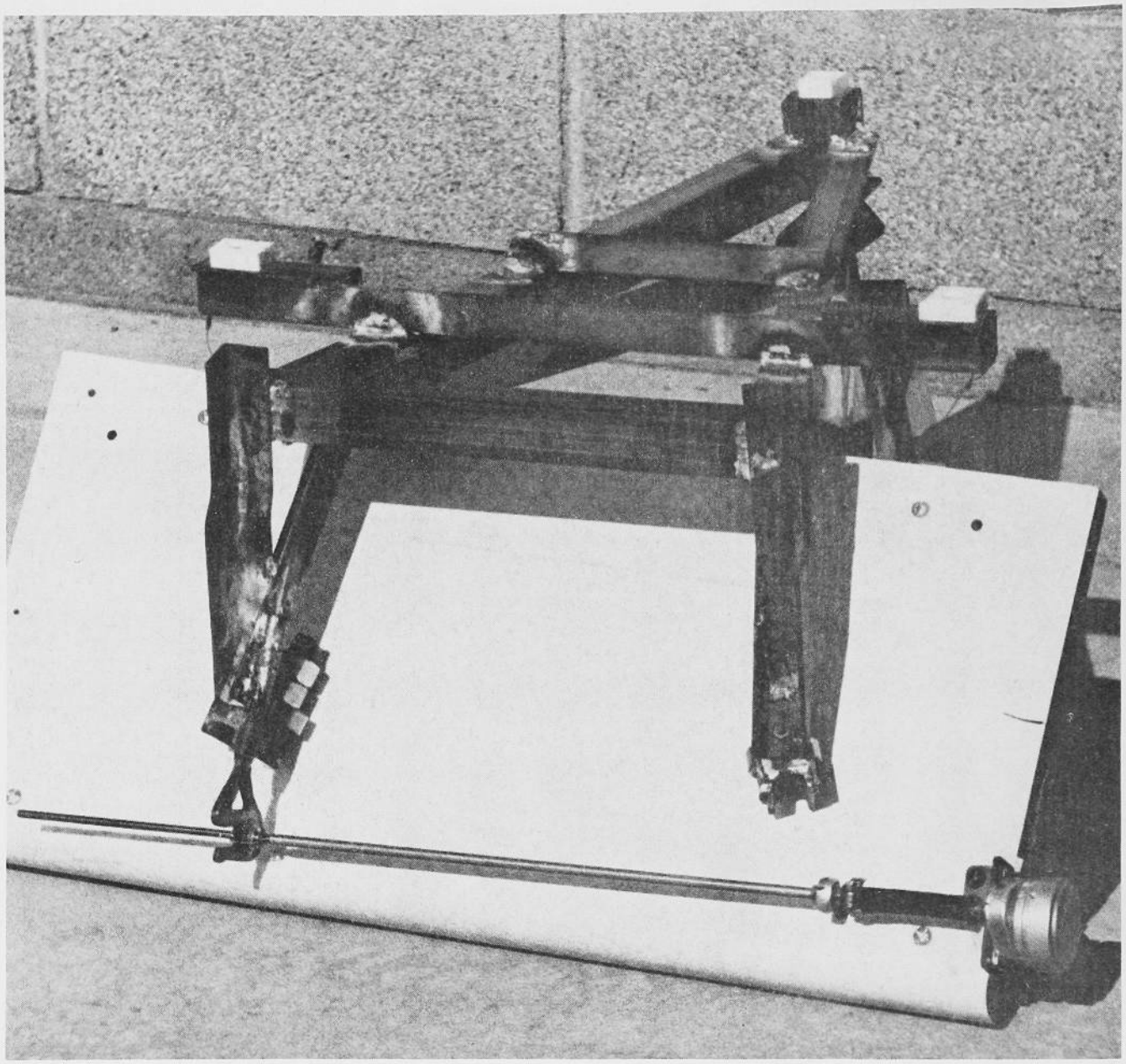
While the Poncet configuration provides a convenient, low platform, there is no reason why an equatorial platform could not be based upon a fork, German or any other conventional mount type.

Guiding Requirements

Astrophotography is a staggering undertaking for the beginner. Even with a proven system, the difficulty of keeping a stellar image stationary on a piece of film for a long period of time is enormous — and increases with focal length. Exposures with 50mm or shorter lenses are merely so-so difficult. Exposures with a 135mm telephoto lens are about two and a half times tougher, and prime focus for my telescope at 1375mm was a real mind-bender.

Declination drift can be corrected by slow motions on the Dobsonian altitude and azimuth axes — but this leaves you with three controls to manipulate instead of two and is generally an unsanitary solution. My solution was to tilt the whole structure in a north/south direction. This does not provide pure declination movement except along the local meridian, but the small additional R.A. corrections required have proven to be no problem at all. The idea for the strap





hinge device that I used was borrowed from a friend who uses similar devices for leveling camera and telescope tripods. I was able to take some good 135mm piggy-back photos with a socket wrench on the hinge screw, but the run around/stoop/twist/run back procedure was a real killer. The current model is driven by an electric motor and controlled from a paddle at the eyepiece just like at Mt. Palomar.

My R.A. drive is unusual in that it uses a 12 VDC motor directly powered by the car battery — no inverter or frequency corrector. The R.A. rate is set with a simple pot on the control paddle and (+) and (-) corrections are made with buttons which bypass the pot for (+) and increase the resistance for (-). The system is cheap and works well, but I would use a synchronous motor system with conventional drive corrector next time to decrease the guiding workload.

One guiding problem peculiar to Poncet mounts is that the center of gravity of the assembly is usually far above the rotational axis. When the CG goes over the top of the axis, the mount drive system, pre-loaded to one side by gravity, decides to go to the other side with a pronounced "thunk" and a big shift in image alignment. Slop in the drive components should be held to a minimum. I also use my Anti-Backlash Fixture (ABF) — a ten pound brick placed on one side to shift the CG so that it won't cross the rotational axis.

Peculiar Poncet Problems

There are several possible geometric configurations for a Poncet mount. The article by Adrien Poncet in TM#10 is a good reference for selecting a configuration for a given latitude. Mine was constructed along the lines of the examples by Robert Cox in TM#8 and works well at my latitude of 34° N.

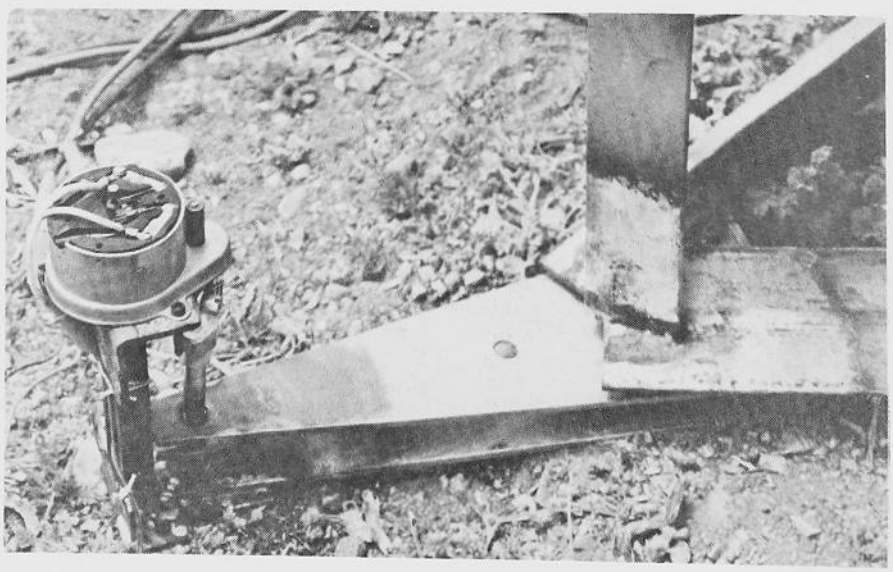
An early consideration in designing a Poncet mount is how long you intend to track, or how far you are willing to tip your telescope. My geometry will allow 90 to 120 minutes of tracking, but I currently have stops placed to allow only one half hour of tilt. This keeps me from walking away and forgetting while the mount chugs along and finally dumps the telescope on the ground. So far, my pictures have been of the brighter Messier objects and 30-minute exposures have been plenty.

As might be obvious to the geometrically inclined, the smoothness of the tracking depends on the smoothness of the plane surface and the

roundness of any rolling bearings in contact with it. I use a piece of Formica® countertop and a pair of sealed ball bearings which run on their steel outer races. Imperfections in these surfaces show up as excursions in declination as the north end of the mount bounces up and down over the irregularities.

One version of the mount employed urethane roller skate wheels as bearings, but even used ones proved to be too irregular and too squishy for stability. One word of caution: The bearing surfaces must be clean prior to a photo session. Dirt can mess up the tracking.

Concerning construction, you need maximum stiffness and minimum friction. My first try at a Poncet was made of wood and used Teflon® on Formica® bearings. The relatively high friction coefficient and the flexibility of



the wooden bearing supports caused the mount to track by jerking to a new position every couple of seconds. Fortunately, a friend got a new oxyacetylene torch for his birthday and was willing to assemble an improved metal version of the mount with increased triangulation for stiffness.

Stiffness is also required in the drive. I tried 3 or 4 configurations including such things as dial cord and hinged push points to allow for the various alignment changes that occur between the base and driven piece. The fine threaded rod and nut arrangement I currently use is excellent for stiffness, but requires a spherical bearing at one end and a universal-type joint to drive it. I use a piece of flexible tubing as a U joint. The longer the moment arm, and the finer the thread, the smoother the operation of the drive.

The drive mechanism. Note spherical bearings prevent backlash.

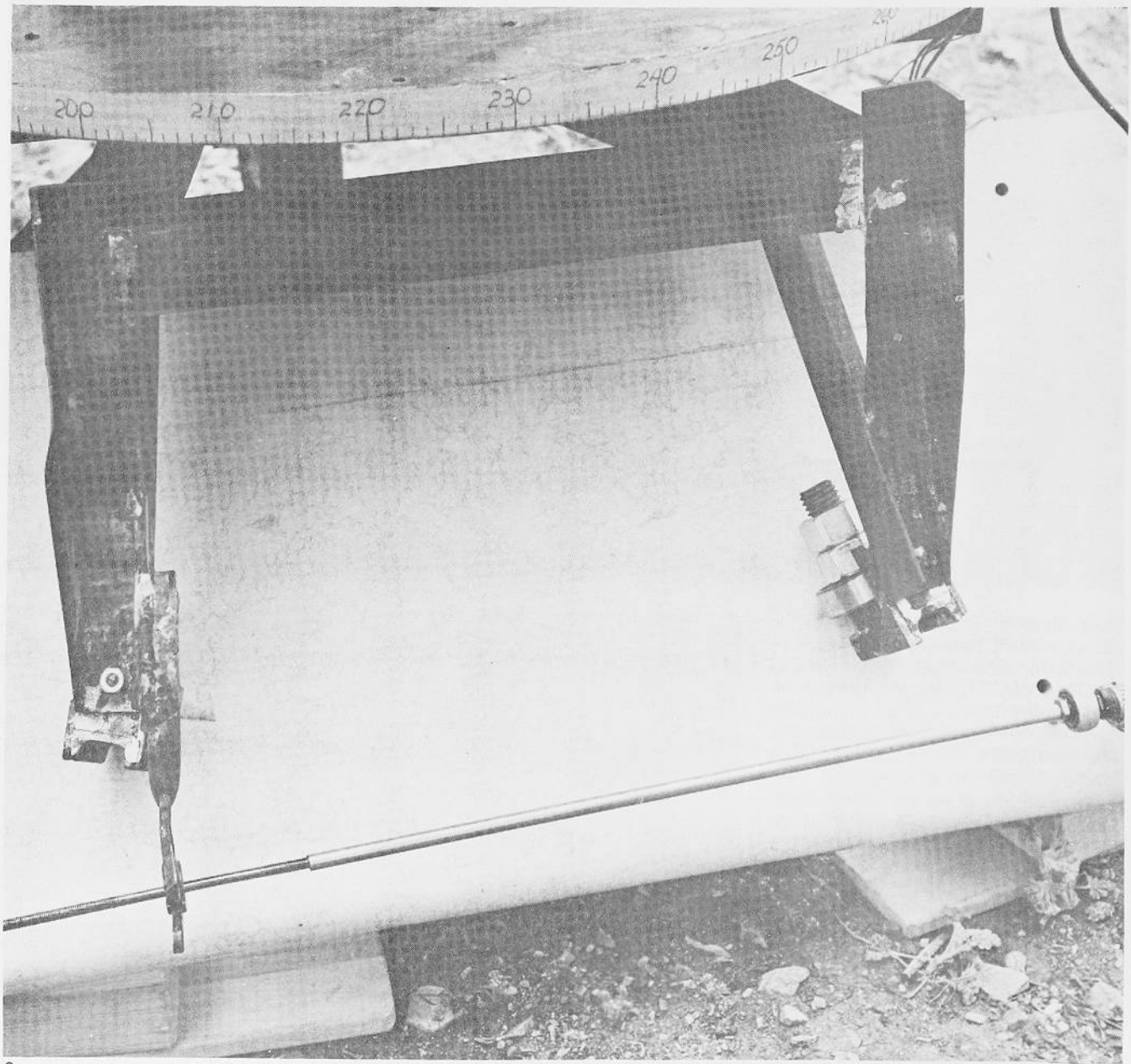
Dobsonian Quirks

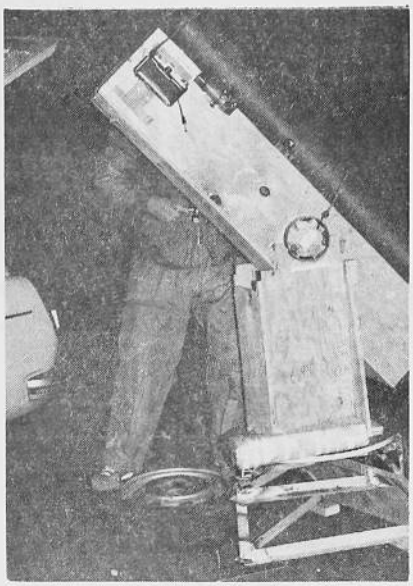
A Dobsonian is, by definition, a stack of stuff held together by gravity. When the gravity vector is allowed to tilt, strange things happen. As the tilt increases, the Dobsonian base will shift on its bearings due to slop in the centering pin, the tube trunnions will slide sideways in their bearings, the mirror will slide in its cell, and finally the whole thing will tip off onto the ground.

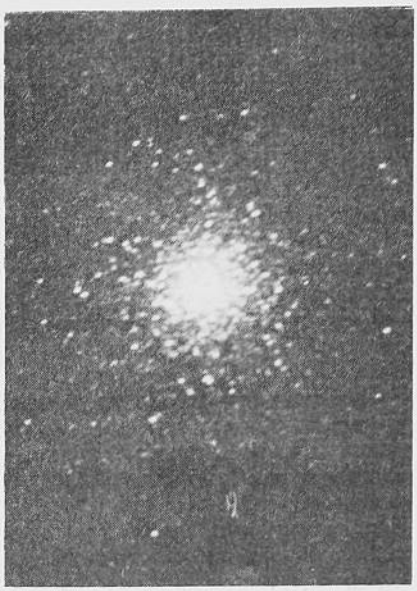
Since I didn't use a Dobsonian-type strap cell for my mirror, I can't report on the mirror's sensitivity to slipping due to tilt. I am certain that only minor changes, if any, would be required to allow a reasonable tilt angle. I used a conventional mirror cell but still found that you must pay attention to securing the mirror without distorting it.

One obvious area of design consideration is to place the CG of the telescope as close to the Poncet axis as possible to minimize the CG movement and load shift. You can approach this by raising the south pivot point to raise the mount axis, and by doing everything you can during construction to balance the telescope tube toward the mirror end, thus allowing a lower, shorter, and stiffer Dobsonian base.

Even the guide system must be considered. I used a separate guide scope because it was cheap and makes composing the picture easier for me. The drawback is that it causes an unbalance







An early attempt at M-13 — not great, but promising. 20 minute exp.

of the two-tube assembly by moving the combined tube CG away from the trunnions. This can't be perfectly counterweighted on a normal Dobsonian and I have to move weights around depending on elevation angle. Flexure does not seem to be a problem for the 30-minute exposures that I've done so far, but an off-axis guider seems desirable from a weight and CG standpoint.

The Joys of Polar Alignment

As with any equatorial mount, the Poncet means good-bye to the days of the 30-second setup. The star drift method of polar alignment for the Poncet is the same as used by most photographer folks for fine alignment of their conventional equatorials. Align the mount axis roughly north/south (in the northern hemisphere), select a convenient star in the south along the meridian, and observe the up/down drift of the star at high magnification as the mount tracks. Adjust the azimuth of the mount until the star stays on the cross hairs. Then select an east or west star and repeat for mount elevation. Since my declination device tilts the polar axis anyway, if I don't get elevation just right at first, it will get better during the night of tracking, providing the azimuth was OK to begin with.

On a good night, I can align in 15 minutes or so, but the learning curve was pretty steep. The first few sessions were a little trying.

Photographic Accessories

I was appalled at what photography did to my budget. Some device is required to hold the film. Although the requirements are not critical, most accessories are designed around a 35mm SLR camera. I spent more on my camera and telephoto lens than I did on the telescope and mount — and I didn't buy expensive stuff. Other necessary accessories include:

- Guider (scope or off-axis) $40-$100
- Camera adapter and eyepiece holder $20
- Lighted reticle eyepiece $50
- Cable release $15

Start throwing in developing tank, enlarger, chemicals, hypersensitizing kit, etc., and the costs go exponential. Please note, however, that these costs are not related to any particular type of telescope. It costs the same to convert a Dobsonian to astrophotography as it does any conventional type.

Impressions

During the past 6 months, I have taken a class in astrophotography and had the opportunity to use two good telescopes available to the school. I even had a couple of sessions on the 30" reflector at the Stonyridge Observatory. All in all, the operational aspects of my Dobson/Poncet while guiding are the same as the other scopes. At the eyepiece, the guiding functions are the same for the Stonyridge scope as for mine. (From the sublime to the ridiculous!) The reset and repoint every half hour is a slight bother — but it's the only real operational difference.

In terms of quality of performance, it is difficult to separate the machine effects from the operator effects. I was able to submit Dobson/Poncet photos for my class which were as good as those taken with the school telescopes. The principal remaining problem with my mount is a periodic variation in R.A. rate with drive screw rotation due to the non-synchronous drive motor. Although this is correctable with the control paddle, it increases the workload. Tracking is rock steady otherwise.

The declination drive has zero slop because it is pre-loaded with the weight of the whole assembly. I prefer it to any other that I have used. The most significant problem is the flimsy Dobsonian base, the main source of wiggles when the wind blows. This is my own fault — and I'll fix it one of these days.

As it is right now, I have been able to take prime focus and piggy-back shots that compare favorably with those taken by friends and acquaintances using conventional mounts of reasonably good quality. I am also encouraged that between me and the scope, one of us seems to be getting a little better as time goes on.

Where From Here?

I have convinced myself that a Poncet-type mount can be used for high quality, serious, astrophotographic work. The pictures I take now are good but not great, and wind tolerance is low. I plan to continue my own study by making refinements in the R.A. drive smoothness and stiffness in the old Dobsonian structure. With these few refinements, I expect to be able to do as well as the most expensive equipment now available for my size scope.

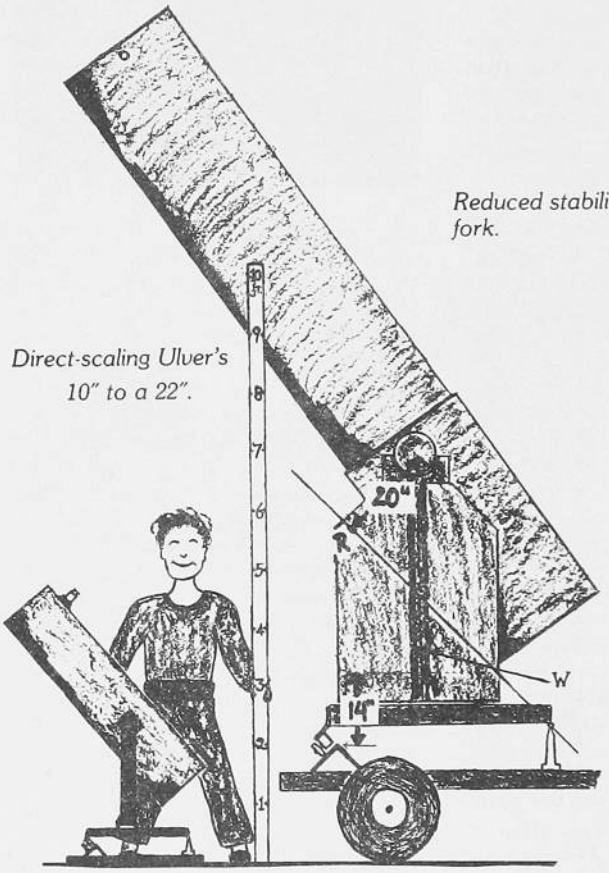
Whenever I take this thing out to an observing site, I see more and more Dobsonian and other alt/az mountings. Many people, like me, have bought or built Dobsonians as first telescopes and I find a lot of these people are interested in acquiring photographic capability. I have been involved in other hobbies where new technology has reduced costs and caused a large increase in participation. Based on cost/aperture for equivalent capabilities, I fully expect the Dobson/Poncet arrangement, or a descendant thereof, to become very common in the next decade.

Now that all this stuff is feasible, maybe I'll ask Santa for a 17.5" mirror set.

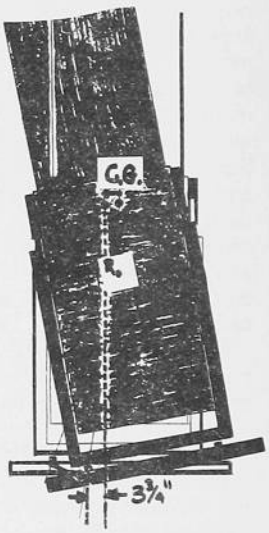
Dick Houskeeper
436 W. Ave., J-10
Lancaster, CA 93534

Editor's Note: I saw Dick Houskeeper's telescope at the 1981 Riverside meeting and was duly impressed with it. I even took about a dozen pictures of it. In fact, his scope got a 2-page spread in the original, and longer, version of the Riverside story. When I had to cut the article down for space, I dropped his scope because by then I knew he was working on this article for TM. Relative to my comments on page 3 of TM#10 letters column, Dick Houskeeper is the first to have done it that I know of. As for Houskeeper's predictions — I agree 100%. The Poncet is one of the reasons I put my own 20" on a Dobsonian mount.
— RLB

A Poncet/Dobson Hybrid Mounting for a 22" Reflector



Direct-scaling Ulver's 10" to a 22".



Reduced stability in a tipped Dobsonian fork.

My 22-inch reflector moves on *four* axes.

In *Altitude*, it moves with characteristic Dobsonian smoothness on Teflon® pads.

In *Azimuth*, the wide fork mounting turns on a seven foot ring. The upper component rolls on the lower one on appliance roll-outs. (These will soon be replaced by ball-bearing wheels because an observer can presently make adjustments in azimuth from the top of the tube only when viewing within 30° of the horizon, owing to the excessive friction of the roll-outs.)

In *Right Ascension*, it tracks equatorially for over an hour. Its infrastructure owes its design to both the Poncet Equatorial Platform and to the Porter Split-ring Mounting.

In *Translation*, the fourth motion, the word "axis" is, I must admit, less appropriate than the word "axle." On the front axles of a long-gone Ford Maverick, the telescope rolls along highways and byways — and even up the winding trail to the top of Breezy Hill.

The mounting and three-footed base are integrated into the design of the trailer in such a way that it is difficult to decide where the telescope ends and the trailer starts.

But the freedom to move in any one of these four directions has not been gained at the expense of stability in the other three. In fact, short of setting up in an earthquake zone, it seems to be very difficult to detect vibration in the tube or any undesired motion in the mounting. For instance, the azimuth motion, even though it is rather stiff at present, is free of backlash and unaffected by the tilt necessary for equatorial tracking.

Basic Design Considerations

Is it possible to get a *large* mobile telescope with equatorial tracking simply by sandwiching a scaled-up Poncet platform between a large Dobsonian reflector and a trailer? To phrase the same question in another way: Could Dick Houskeeper's Photo-Dobsonian (See "Riverside '81" in TM#12 and the article in this issue) be scaled up two to three times — and then mounted on a trailer? In considering designs last fall for my telescope, I came to the conclusion that the answer to both questions is an emphatic NO!

The result of such an approach, I believe, would be unstable, untrailerable, and just plain unsafe. Most of the reasoning behind this conclusion is based on the locations of the centers of gravity and rotation, absent so far from the literature on the Poncet mounting.

At the time I worked out my design, the largest telescope on a Poncet platform to appear in a published photo was a 10" f/6 reflector mounted by Irvin Ulver of Camas, Washington. Now imagine this telescope scaled up 2.3 times in order to support Gerard Pardeilhan's 22" Dobsonian (shown in *Sky and Tel.*, April 1980, p. 341). Even if one optimistically ignores the geometric effects of scaling (which, of course, is what would prevent real horror-movie giant spiders from moving without breaking their legs), four serious objections remain to a hypothetical large Dobsonian/Poncet hybrid.

Starting with the least serious objection, the hypothetical telescope would be unreasonably high when placed on a trailer. Notice that the mirror end of the tube can never go below about waist level.

Second, wouldn't the classic, boxy, Dobsonian fork flex and distort on being tilted?

Third, and more seriously, the center of gravity of tube plus fork is located well above the effective polar axis, creating a potentially lethal combination of height, mass, and dynamic instability. The arrangement is dynamically identical to a large German equatorial mounting with a long cross axis meeting the polar axis at a point labeled "R" on the drawings — and having an insufficient and improperly placed counterweight. A corresponding well-balanced equatorial mounting would have a heavy counterweight near the shoulder of the man in the drawings.

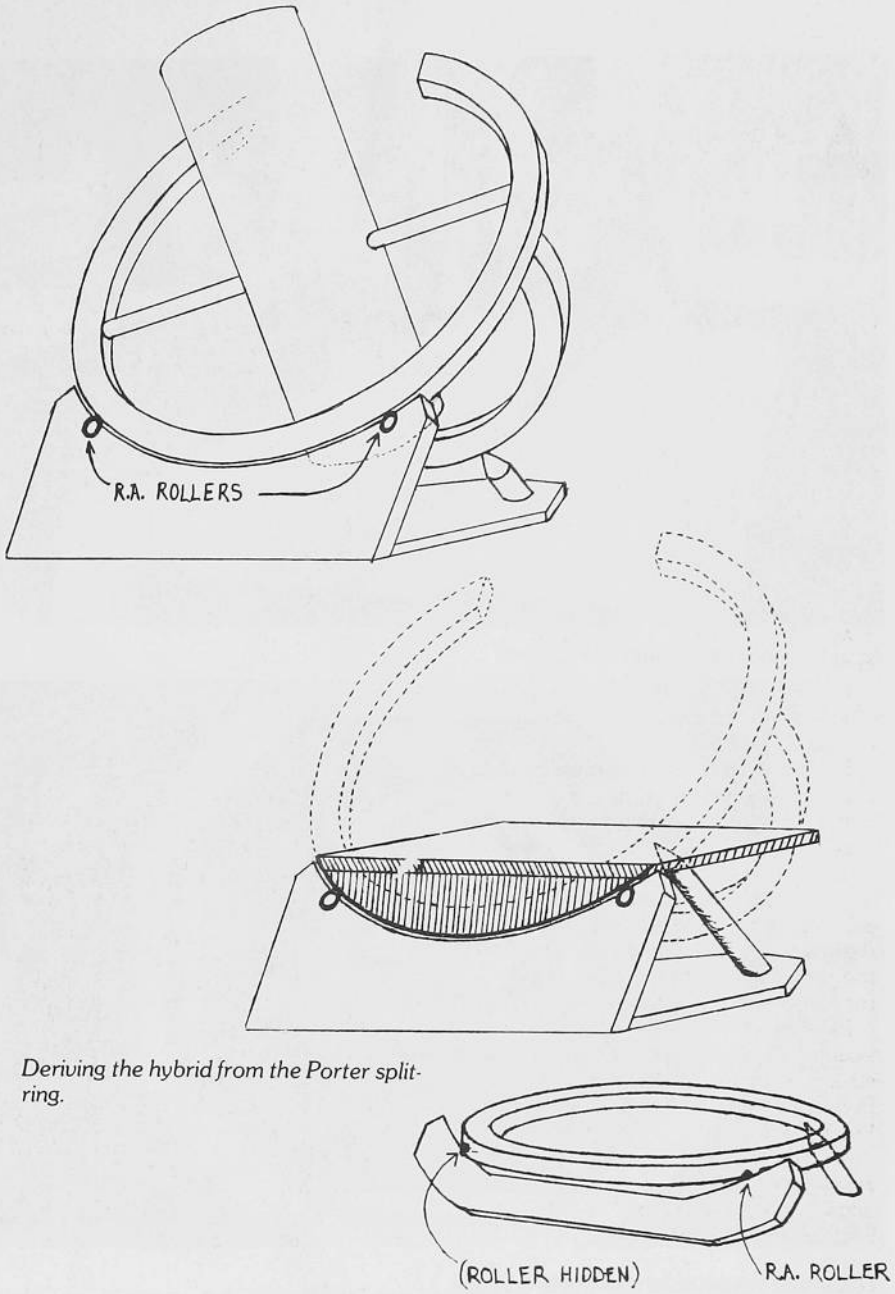
Instead, the hypothetical telescope is stabilized only by the insufficient moment of the fork plus upper part of the Poncet platform, which is smaller than the mass of the tube and centered around a point ("W") closer to the axis of rotation than the center of gravity of the tube.

The fourth objection becomes obvious when you consider tilting the hypothetical hybrid telescope, as happens when it tracks. After one hour of tracking, or about 10° of rotation in the vertical plane for the assumed latitude of 45°, the tube's center of gravity has moved outward to a point almost directly over the outermost support pad at the base of fork, which has moved steadily the other way during the hour of tracking. Note: This problem gets worse at lower latitudes.

While objections one and two merely point to a loss of the classic Dobsonian's efficiency of design, objections three and four taken together spell imminent catastrophe! I'll leave the details to the imagination of the reader.

My solution to these problems came as the result of a chain of thought touched off by a note in *Sky and Telescope* (February 1980, page 166) by Alan Gee, one of the authors in *ATM-3*. He pointed out that simple transformations of Russell Porter's time-honored split-ring equatorial mounting result in equatorial platform designs. Following his line of reasoning, I developed my own variant of the Poncet mounting.

Imagine a telescope mounted in a Porter split-ring mounting. Slice off all the superstructure and replace it with a platform. This is the Poncet as it's usually built. I pursued the evolution in a different direction — replacing the platform with a ring. The ring is equatorial, just as the Poncet platform is equatorial. With the R.A. rollers attached to it, however, it offers two major advantages. First, it serves as the base of a very wide, stable alt-azimuth fork mounting, and second, it allows the overall center of gravity to be much lower, since the mirror end of the tube can swing down through the ring into the space beneath the ring.



Deriving the hybrid from the Porter split-ring.

Furthermore, the equatorial ring mounting and the equatorial platform share an advantage described in the following way by Mr. Gee: "The moving parts are fully constrained, [and] the rollers are loaded radially . . ." I believe this structural advantage is important when the mass above the R.A. bearings is large. In my case, it amounts to 900 lbs.

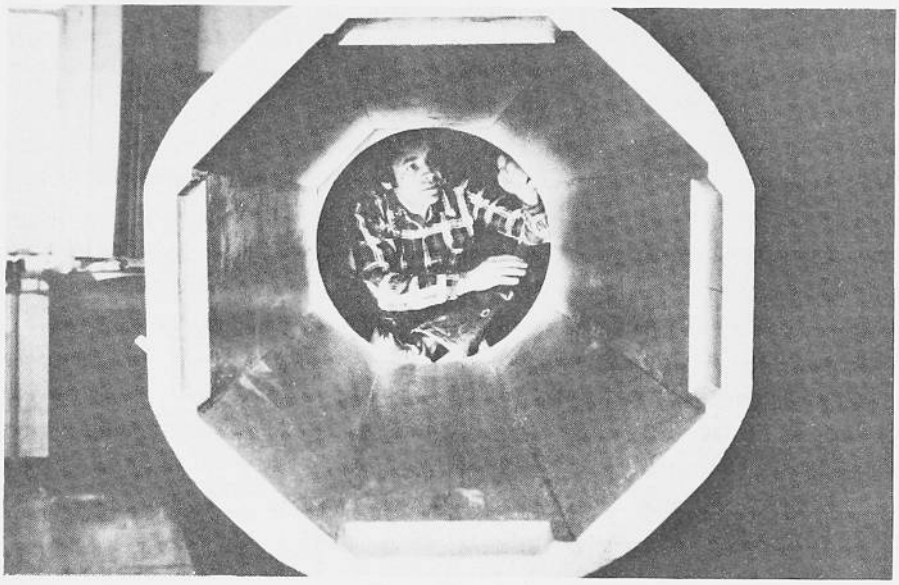
The basic geometric constraint in the design of the equatorial ring mounting is simple and flexible. The rollers attached to the ring roll up and down the curved track at the north end of the fixed support structure during equatorial tracking. The curve of the track defines a large cylinder inclined at the local latitude angle, so that the axis of the imaginary cylinder is the polar axis of the mounting.

The southernmost point of the ring must pivot at the point where it intersects the axis of the cylinder. If such is the case, equatorial tracking is guaranteed. If, for instance, I had made my ring too small, I could add an extension to its south end to intersect the axis of the cylinder without compromising the equatorial motion.

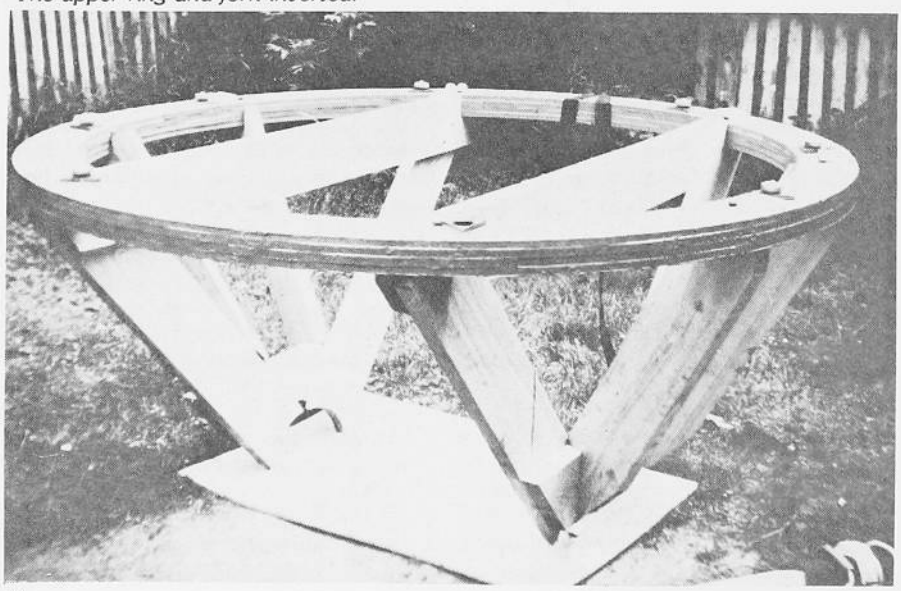
I could even replace my compact rollers with huge ones, forcing the whole ring to tilt toward the south. Provided these rollers moved up and down the segments of the correct cylinder, the ring would still track accurately.

The ring under my telescope has an outside diameter of 86″ and an inside diameter of 73″. With the altitude axis 37″ above the top surface of the ring, and with a structurally insignificant cut-out for the mirror end of the tube, this ring can accommodate 52″ of the tube's length measured down from the altitude

The lower end of the tube completed.



The upper ring and fork inverted.



Construction of the Mounting

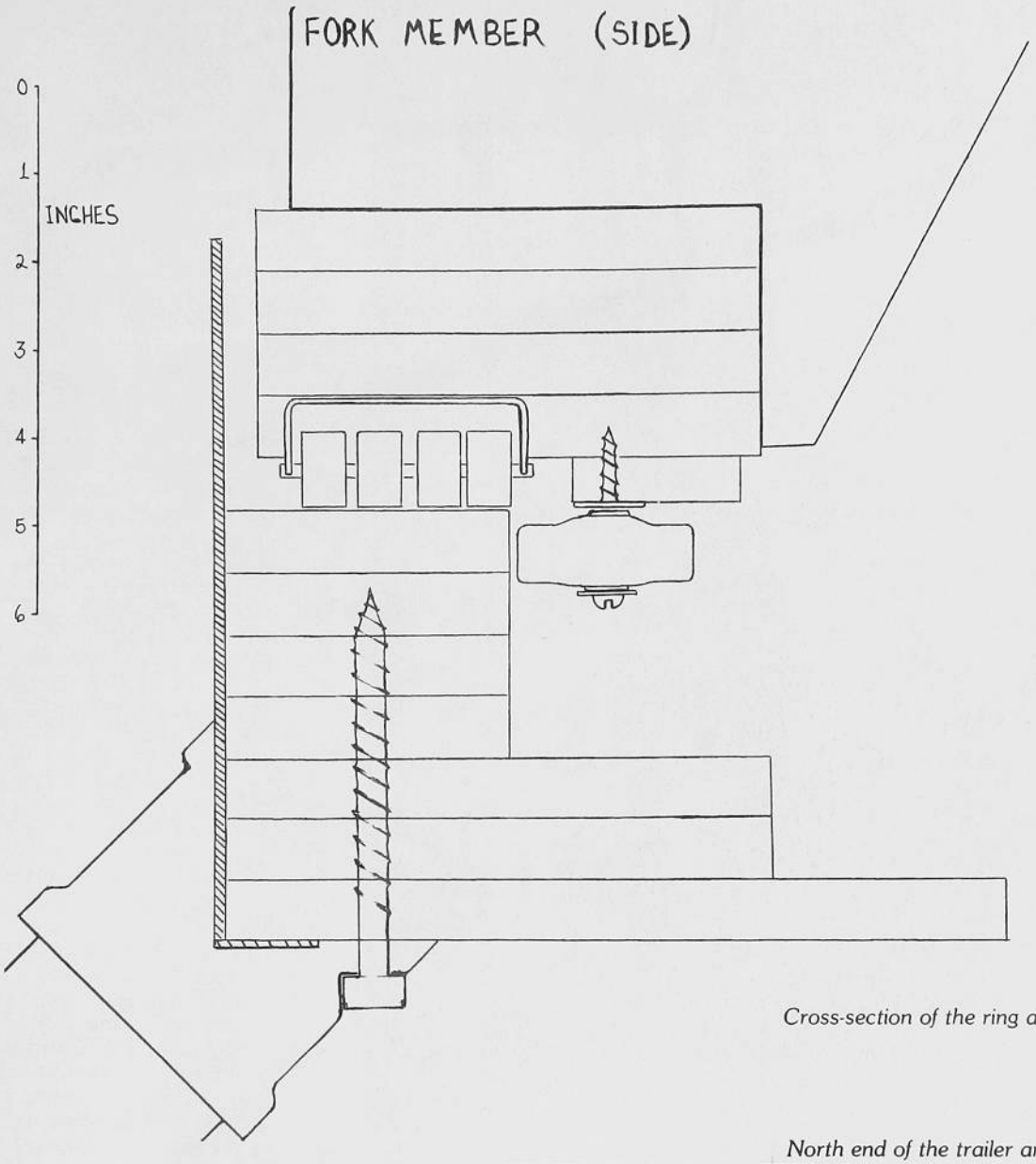
This telescope was conceived as a wood, glue, and hand-tools project. However, when I finally got around to calculating the weight of a solid wood ring laminated from seventy odd four-foot long, nine-inch-wide arcs of particle board, I got a rude shock. Six hundred and thirty pounds! I quickly realized that steel could save me a lot of weight. An 80 lb. 8″ wide strip of ⅛″ thick steel stretched around the outside of the laminated wooden ring allowed me to remove 310 lbs. of wood from the rim of the ring. This reduction in weight still retains adequate rigidity against vertical loading.

I cut the fork members out of strong oak 2 x 8 timbers, and assembled them with lag bolts and glue. The slanting members are placed so as to spread the weight of the telescope as evenly as possible around the ring and preserve stability when tipped for tracking. The design of the fork came to me after I studied, in succession, Richard Berry's 20″ reflector (see TM#7) and articles on Herschel's reflectors in the March 1981 *Sky and Tel.* I was fascinated by the mountings of Herschel's large reflectors, which also had eight-member forks based on a large horizontal ring.

I wanted large aluminum altitude trunnions on my tube for the Teflon® at the top of the fork to run on, but in my small, remote town, the only aluminum available comes as doors, windows, or in light alloy automobile wheels. I chose the wheels in preference to windows!

I cut each of two wheels in half along a saddle-shaped curve (actually along 720° of sine curve) using a hack saw and a saber saw. Epoxy and bolts provide a very strong attachment to the tube and their motion on Teflon® pads is extremely smooth. The rim of the wheel is made to order for absorbing the sideways thrust when the fork is tilted, and I arranged the Teflon® to "roll over" a bit from top to side of the fork.

The trailer bed doubles as the infrastructure of the Poncet platform,

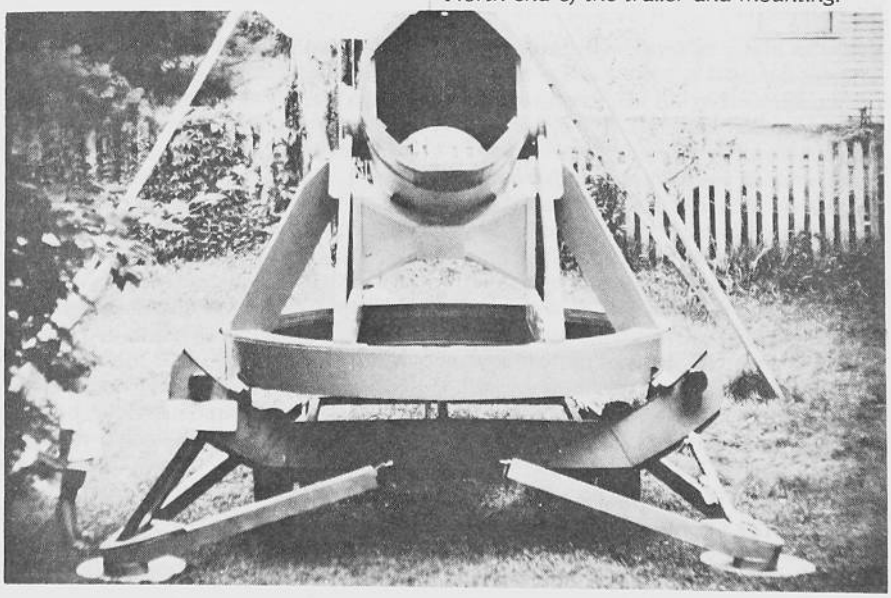


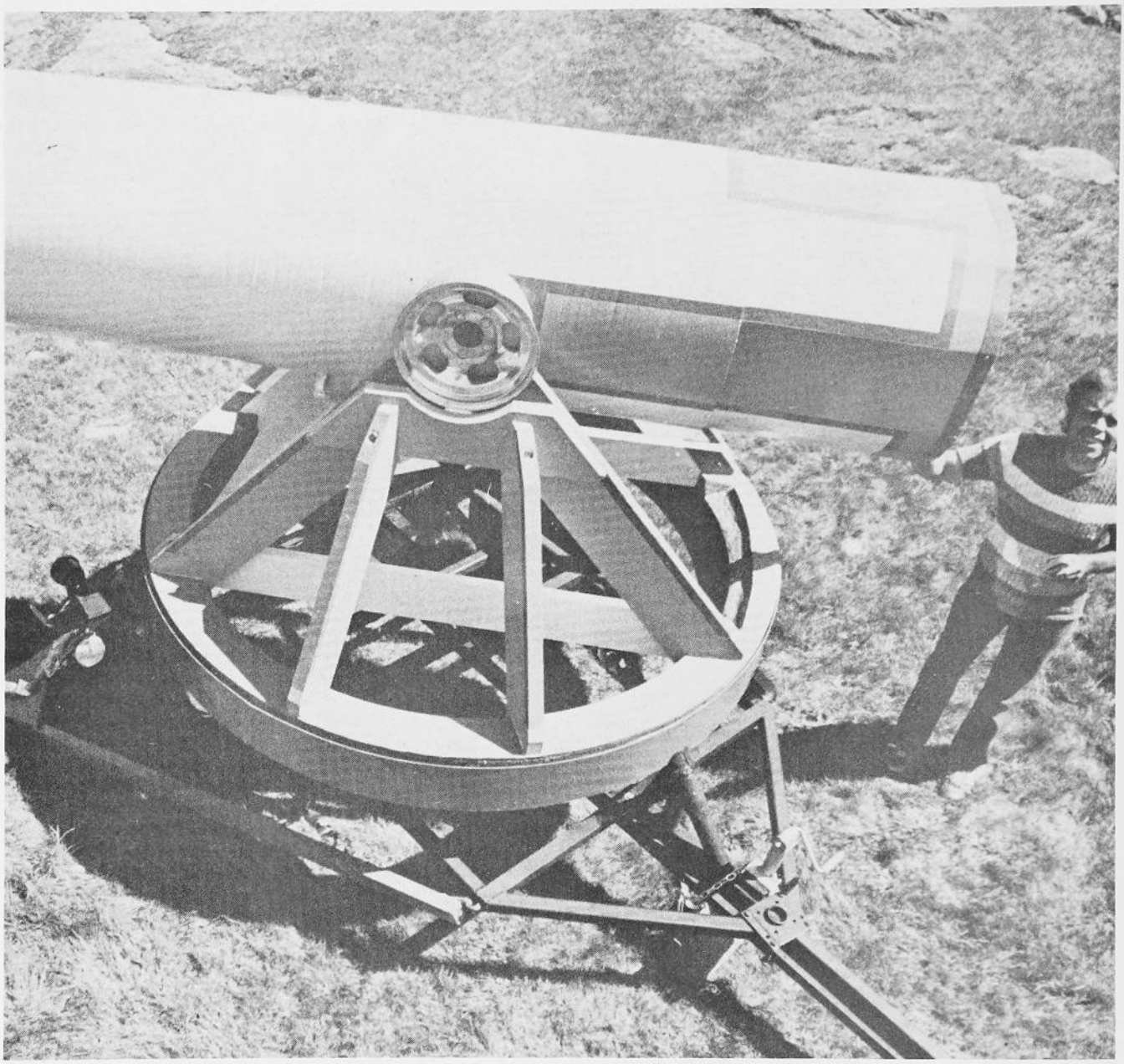
Cross-section of the ring at the pivot.

preserving the correct relationship between the pivot at the south end and the track at the north end. This structure does not have to be stiffer than required for road safety because the load path carrying the weight of the telescope to the ground during operation resembles axis. The radius of the cylinder defined by the track under the ring is 61", and this means that the length of the curved support structure providing the cylindrical track must be approximately 102". I doubt that a larger ring will ever be mounted on a trailer, because the width across the corresponding track would force one to display a "long wide load" sign and rotating yellow beacons!

This is not to say, however, that a larger mobile telescope could not be mounted in this way. I believe my ring and fork, for example, could eventually handle a 32" f/4.5 reflector.

North end of the trailer and mounting.





that of a standard tripod. Its three feet support the fixed structure at the stress points. Adjustable but fully triangulated struts attached on arrival at the viewing site support the curved track at two widely-spaced points nearly underneath and along the direction of stress, the points where the ring bears on the track.

The third support point of the ring, the pivot, is also directly supported by a jack welded to the trailer bed. The wide-set continuous load path from the telescope to the ground is the basis of the stability of this instrument.

The trailer is thus an integral part of the mounting. One could remove the wheels, tongue, and springs after the telescope was set up — but no more. It is thus irrelevant to consider operating this telescope off its trailer.

I originally designed the trailer to be made of wood with steel at stress points. However, just before starting to build it I discovered a half-finished trailer being built as a welding class project in the secondary school where I teach physics. The welding teachers agreed to modify it according to my specifications, which nonetheless, must have seemed rather weird and unreasonable to them. This had the advantage of producing a more compact and durable structure beneath the ring.

This method did have one disadvantage. The $\frac{1}{8}$" x 3"-wide steel sheet used for the surface of the curved track buckled slightly where it was welded down the main members. Although the 61" radius curve was simply traced with the "two nails and a stretched wire" method and then flame cut, most of the plus or minus $\frac{1}{16}$" error in the curve occurred during welding. Thinner metal bonded to a thick hardwood track could be more accurate, though I won't need to grind the curve of the track smooth until I attempt photography. Given the size of the mounting, the track deviations amount to about 4 minutes of arc — not enough to interfere with tracking for visual purposes.

The Tube and Optical System

How does one accommodate a 13.5-foot focal length in a 12-foot tube? Since I could not obtain a concrete form — or any other tube — longer than this, and since I needed to protect the diagonal from dew and the eyepiece from stray light, I built an internal tube of laminated particle board extending 25 inches beyond the lower end of the Sonotube. I chose a 30" diameter Sonotube in order

to have room to build this internal structure and to leave space for internal stiffening rings at the upper end. This diameter made it practical to work on the tube from the inside. It is also easy to keep the inside of the tube clean — you just push a vacuum cleaner into the tube and then climb in after it!

The internal tube is octagonal inside and was shaped by laborious filing to mate exactly with the inside of the Sonotube. Most of its 78″ length, which takes it up past the altitude trunnions, is overlap inside the Sonotube for rigidity. This wooden structure weighs 230 lbs., which lowers the center of gravity (52″ from the bottom end) and provides a solid base on which to bolt the altitude trunnions.

While the conventional hinged Dobsonian tailgate provides a convenient way to insert and remove the mirror, this does not adapt well to an octagonal tube. I retained some of the advantages of the tailgate by designing a mirror support triangle of welded one-inch steel tubing to fit the octagonal opening. The triangle carries both an eighteen point flotation system and a protective octagonal housing of 1 x 2-inch pine and ¾″ plywood. Inside this housing, the mirror rests more or less permanently in its Dobsonian-type edge support sling.

I rarely touch the mirror itself, as the triangle, housing, and suspension form a unit which is stored in a soft case of impermeable fabric. It lifts in and out of the tube in one piece. The bottom two points of the triangle pivot on support blocks inside the end of the tube, and the top point clips securely into place after insertion of the mirror unit.

Were it not for the Dobsonian concept of removing the mirror from the telescope to the safety of the car, the 22-inch mirror in my telescope would not exist today. It was made in 1977 by John Dobson and Gerard Pardeilhan, president of the San Francisco Sidewalk Astronomers, for Gerard's telescope "Long Eye." Most unhappily, Long Eye was destroyed when the tongue of its trailer sheared off. The mirror was in the car. Gerard rebuilt the telescope and called it "Phoenix." My telescope is thus in a way a third reincarnation, so I call it "Phoenix II." In keeping with the moral of this story, the trailer under Phoenix II has a heavily reinforced tongue!

The telescope travels with the front end of the tube lowered over the trailer tongue, directly behind the car's rear window. This has turned out to be stable and aerodynamically efficient. The scope can be set up at the viewing site without heavy lifting. I have done it without assistance.

Conclusions

Phoenix II traveled a total of 1850 miles in the month since I finished construction. It has already participated in six marathon observing sessions at four widely spaced sites. The views I have obtained, plus the reactions of experienced amateurs and members of the public, have already amply rewarded me for the labors of construction. The field of view of more than 40 minutes of arc provided by my 38mm Erfle, together with the 22″ aperture mean a great deal of starlight enters the eye. M-13 is resolved to the center, and spiral structure is evident in M-51. I was particularly thrilled to see color contrast in the Trifid Nebula and the dust lanes in the reddish part.

The equatorial tracking, so far powered by hand-turning a small pulley, allows a dozen or more viewers to take their turns without any interruptions for re-aiming the telescope. This is very helpful when showing deep-sky objects to lines of people. I'm now designing an automatic drive which will probably be of the "curved bolt" type (*Sky and Tel.*, October 1980, p. 334).

The portability, stability, tracking, performance and handling qualities realized so far have encouraged me to plan much further development. In particular, I am keen on refining and motorizing the tracking and developing full photographic capability. In the meantime, many celestial sights remain to see as I have never seen them before!

Steve Dodson
RASC, Ottawa Centre
882 McIntyre St. W.
North Bay, Ontario
Canada P1B 3A3

■

Dual Axis Equatorial Platforms

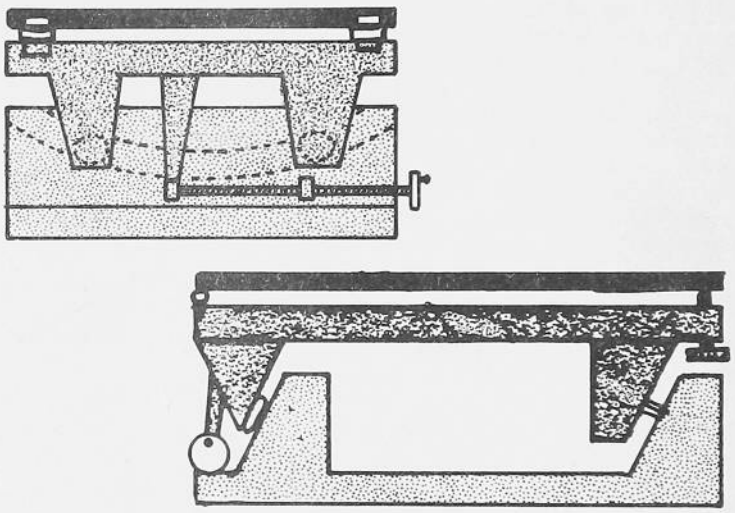
By installing a tilting platform on top of an equatorial table, it is possible to mimic a declination slow-motion suitable for astrophotography over a significant fraction of the sky. All regions near the meridian (plus and minus 2 hours of the meridian) and near the equator (plus and minus about 30°) then show a near-correct declination motion when the table is tilted. Because such a table is triangular, and because a Poncet-type platform is also triangular, good stability is easy to attain.

For guiding long exposure deep-sky photographs, it is necessary to make declination corrections. However, one of the deficiencies of the Poncet-type platforms, as they have been so far described, is the lack of an adequate motion other than right ascension.

If you stack a Dobsonian telescope directly on top of a Poncet platform, the most obvious place for adding a second motion for guiding is the altitude axis. Aside from complicating the Dobsonian mount, this offers a motion at right angles to the direction of tracking only when the telescope is pointed at the meridian. The region of good declination tracking is a small fraction of the sky.

By tipping the polar axis, as Dick Houskeeper demonstrated at the RTMC in 1981, a better declination motion can be provided. Unfortunately, while this is correct for both the meridian and at points on the celestial equator, over a period of time, the polar alignment suffers in altitude.

What are the requirements of a declination motion? First, the axis of rotation must be perpendicular to the polar axis. As noted above, this is true for motions in altitude only in the meridian, and for rotation of the mount about an east-west line (as in Houskeeper's arrangement) only in the meridian and along the celestial equator.



For correct declination tracking, there is a second requirement: that the axis must be perpendicular to the object being tracked. This is simply not possible with a Poncet platform because the hour angle of the platform surface typically only moves through the range between -45 to +45 minutes. But a tiltable platform atop an equatorial table satisfies the first condition for a declination motion fully, and through the range of hour angle of the platform, also satisfies the second condition. A tilt-table second motion will give a correct declination slow motion for both the hour angle of the platform and the equator.

For parts of the sky near either the equator or the hour angle of the platform, which is usually also near the meridian, the second axis will produce a good approximation of the declination motion. Since most long-exposure deep-sky photography is carried out near the meridian, and since the greatest area of the sky is near the equator, most objects suitable for photography can be tracked with a dual-axis equatorial platform.

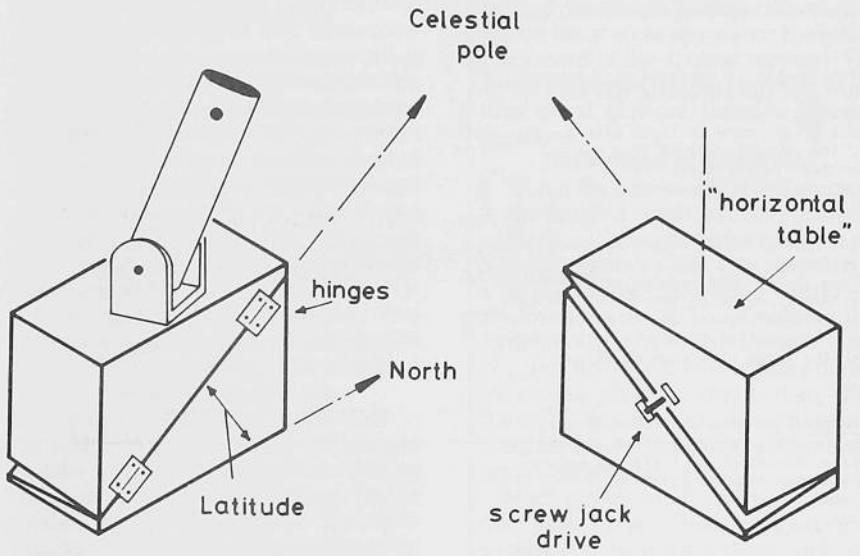
For maximum stability on a classical Poncet platform, the tilt table should be hinged at the roller end, and the tilt driver should be placed over the pivot point. The platform itself may be reduced to a skeletal structure, with the top of the tilt table becoming the new instrument mounting surface.

One advantage is that a Dobsonian telescope placed on the dual-axis table need not be modified, except, perhaps, for some method of clamping its az and el motions.

Richard Berry
c/o TELESCOPE MAKING
625 E. St. Paul Ave.
P.O. Box 92788
Milwaukee, WI 53202

■

A Bending-Pier Telescope Mount



Much of the stability of alt-az mounted telescopes, like the Dobsonian telescope, results from concentric gravity loading of the altitude and azimuth bearings. The counterweights necessary for most equatorial mounts often introduce unwanted vibration to the telescope. Equatorial telescope mounts are, therefore, often over-engineered, relative to the telescope size, ensuring that the cost of large telescopes becomes truly "astronomical." As the Russian 6-meter BTA and the Mt. Hopkins MMT have broken the tradition of super-large equatorial mounts, the next generation of professional telescopes will surely be alt-azimuth mounted.

Unfortunately, for many amateur purposes such as astrophotography and photoelectric photometry, an alt-azimuth mount is unsuited for long-term tracking of stellar objects. One way around this is to place an alt-azimuth mount on an equatorial mount where the alt-az motion allows every object above the horizon to be easily located while the equatorial mount follows the object once it is in the eyepiece.

One such equatorial mount suited for use with alt-az telescopes is the Poncet. The only disadvantage of the Poncet is that the drive mechanism, which usually consists of a metal strip or rod acting against the horizontal table, produces a motion that is not always perpendicular to the equatorial motion and is often cumbersome.

Enclosed are drawings of a telescope mount which combines stability and ease of construction. The mount is a hybrid of the Haig mount in that the polar bearing consists of two good quality door hinges placed well apart for stability. The drive mechanism is also that of the Haig mount, i.e., a threaded rod moving in a fixed nut and against a metal plate forming a "screw jack" to lift the top half of the mount and the telescope against gravity and about the polar axis.

This type of mount combines stability with the "horizontal" surface of the Poncet. The stability is achieved by placing the hinges and the screw jack drive at the corners of an equilateral triangle. There are no counterweights or appendices to vibrate, and the "bearings" are gravity loaded to avoid backlash in the drive.

The mount is most suited for low latitudes, and unsuited for high latitudes, as the height of the pier is given by:

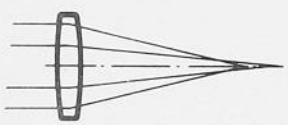
$$\text{height} = Y \tan(\phi)$$

where Y is the north-south length of the pier and ϕ the latitude. Because the function $\tan(\phi)$ goes to infinity as ϕ goes to 90°, it is obvious that this mount is suited for latitudes less than about 60° north or south. The east-west dimension of the pier is determined by the rate of the screw jack and the number of threads per inch of the bolt. This is discussed in TM#8, and can be scaled from that prototype.

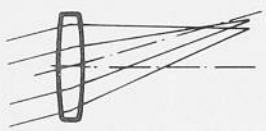
Graeme White
35 Young Street
Annandale, 2038
N.S.W., Australia

■

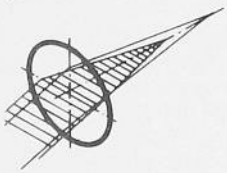
Nine Telescope Systems Compared



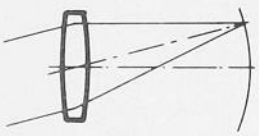
Spherical aberration. Light rays entering at different heights in the system come to a focus at slightly different points on the optical axis. The light entering the system parallel to the axis, will not be concentrated in a point but will form a spot.



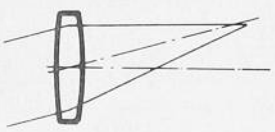
Coma. This aberration can be compared with spherical aberration, with the difference that coma occurs outside the optical axis.
Coma appears as a bright core of light with a spreading tail. The word is derived from the Greek expression for flowing hair.



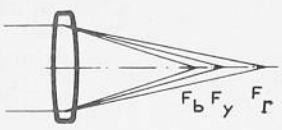
Astigmatism. This aberration is caused by the difference in refraction of a lens or mirror surface in a plane through the imagepoint and the lens axis and at right angles to that plane. By this, two focal lines are created, one in the meridian plane and one in the saggital plane which is perpendicular to this. The image will show an ellips.



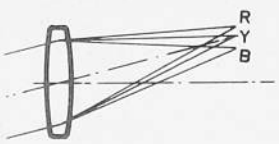
Curvature of field arises when the locus of the sharpest points lies on a curved surface instead of on a flat plane. Curvature of field can be very annoying in combination with astigmatism.



Distortion is a lens aberration in which the magnification of the image varies with the obliquity of the entering rays. The consequence of this aberration is that straight lines appear curved in the image.



Chromatic aberration. Also called secondary spectrum. Light rays of different colour come to a focus at different points on the optical axis, causing colour fringes to the image.



Lateral colour. The magnification of the image depends on the colour of the light. This manifests itself by more or less strong colour fringes outside the optical axis.

FIG. 1 - THE OPTICAL ABERRATIONS

Introduction

Until recently, most optical ray-tracing was carried out by optical professionals because the time-consuming calculations could only be done adequately by a large computer.

Recently, home computers with sufficiently high speed and memory capacity have come on the market. Now ray-tracing, and eventually the design of optical systems, are within reach of interested amateurs. One of the authors has developed a program, in Basic, for the Apple II and carried out the ray-trace calculations for a large number of telescope systems. In this article, we give a broad summary of the results of calculations for nine systems of interest to amateurs.

Image Aberrations

Apart from the manufacturing and assembling deviations, the quality of an optical system is determined to a large extent by image aberrations. Besides chromatic aberrations like secondary spectrum and lateral color, present whenever a system contains lenses, there are monochromatic aberrations. These aberrations, caused both by refracting and reflecting surfaces, were analyzed and described by the German mathematician Seidel in the middle of the last century.

The monochromatic aberrations are called:

- Spherical aberration
- Coma
- Astigmatism
- Curvature of field
- Distortion

Figure 1 gives a schematic view of the optical aberrations. In order to avoid the crushing burden of the exact ray-tracing calculations, Seidel proposed an approximate method of calculation for each particular aberration. While this method is still used in the beginning phase of the design of an optical system,

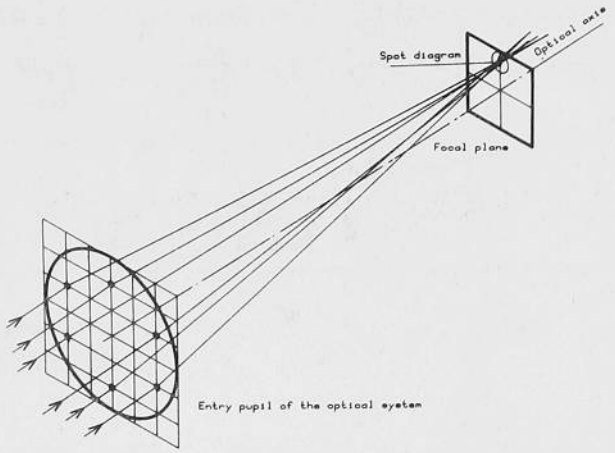


Fig. 2. Principle of the spot diagram.

explicit ray traces are used to optimize the design. For a large computer, the design time is now relatively short.

Simulating the Image with Spot Diagrams

A modern aid for evaluating the image aberrations of an optical system is the so-called spot diagram. In calculating a spot diagram, the basic idea is that a perfect optical system, neglecting diffraction, will produce a point image in the focal plane if the source is a point. When aberrations are present, however, this theoretical aim will not be achieved. The image will be a blur of light represented by the scattering figure. Depending on the magnitude of the aberrations, the size of this scattering figure will be large or small and can have all kinds of shapes.

The purpose of the spot diagram is to simulate the size, the shape and the light distribution. In this way, we can obtain a good estimate of the combined image aberrations.

The principle of spot diagrams is given in Figure 2. A pencil of parallel rays from a point source at infinity passes the entrance pupil of the optical system. The rays, for instance one hundred, are distributed uniformly in an array on the entrance pupil. Each ray is traced through the elements of the optical system to the focal plane. The gathering of the intersecting points of the ray in the focal plane is called spot diagram.

We carry out the calculations not only for the pencil that is parallel to the optical axis, but also for oblique pencils. When the system contains lenses, we repeat the calculations for various colors in order to investigate the influence of chromatic aberrations. Optical aberrations will always produce a certain degree of spread of the spots in the focal plane.

From Figure 2, it is clear that a shift of the focal plane forward or backward causes a decrease or increase of the size of the spot diagram, and also influences its shape. As a consequence, the focal plane will generally not have an exactly defined position. In practice, the position of best focus is chosen in such a way that the spread of the spots is minimal. The determination of the best position of the focal plane requires, therefore, several iterations.

The Method of Calculation

Within the framework of this article, it is not possible to give a comprehensive treatment of the computer program we have developed. Only one elementary example of the ray-tracing method is shown in Figure 3. The formulae in this figure are related to the simplest case, i.e., a ray in the meridional plane during its course through the system. The formulae are in such a form that a program can be easily written for a small programmable calculator.

Much more complicated is the case of the "skew" rays. These rays are lying outside the meridional plane and also outside the plane of the optical axis. They generally do not remain in the same plane during their courses through the optical system. This complicates the calculations causing more calculating time. We used this skew ray-tracing method.

The formulae given in Figure 3 apply only to the refraction and reflection of rays at spherical surfaces. When surfaces are aspheric — for instance, parabolic — it is necessary to apply another method of calculation. With our computer program, an arbitrary number of surfaces can be calculated, even when these surfaces have an arbitrary (but necessarily mathematically well-defined) shape. The program contains standard routines for the calculation of spherical, parabolic, hyperbolic, elliptical, flat, Schmidt and Schmidt-like shapes. The surfaces can be tilted and decentered.

Criteria for Image Quality

The spots in the spot-diagram will generally show a spread. The smaller the spread is, the better image quality will be. As a consequence, it is important to have criteria for "acceptable" image quality. For a telescope, a clear distinction should be made between two criteria: one for visual use, and one for photographic use, taking into account the resolving power of the photographic emulsion.

For visual applications, especially when high powers are used, the spread of the spots must be very small. Approximately 90% to 95% should be concentrated within a circle roughly the diameter of the Airy disk. Because of the small fields when using high powers, only image sharpness round the optical axis is important.

When a telescope is used as an astrocamera, the requirements change. In general, a concentration of 90% to 95% of the spots within a 0.025mm (0.001 inch) circle is sufficient. The other 5% to 10%, however, must have a very low concentration so that the blackening of the emulsion is minimal on that place. These requirements must be met not only on the optical axis, but in the rest of the field.

With the help of the spot diagrams, we found that none of the investigated telescope systems could match these standards.

For the calculations, we assumed a field diameter equal to the diagonal of a 24 x 36mm negative (i.e., 43.3mm). The spot diagrams are calculated for the optical axis (field center), 1/3 the distance to the corner, 2/3 the distances to the corner, and at the corner. The distances from the optical axis are respectively: 0.0, 7.2, 14.4, and 21.6mm. In order to support the judgement of the visual quality of the systems, we also calculated spot diagrams for 4mm as well.

$$\sin i = \frac{H}{R}\cos u_y + \left(\frac{L}{R} - 1\right)\sin u_y \qquad H' = R\sin(i + u_y) \qquad L' = R\left[1 - \cos(i + u_y)\right]$$

$$\sin i' = \frac{n_1}{n_2}\sin i \qquad u'_y = i - i' + u_y \qquad L_e = \frac{H'}{\tan u'_y} + L' \qquad H_y = H' - (L_f - L')\tan u'_y$$

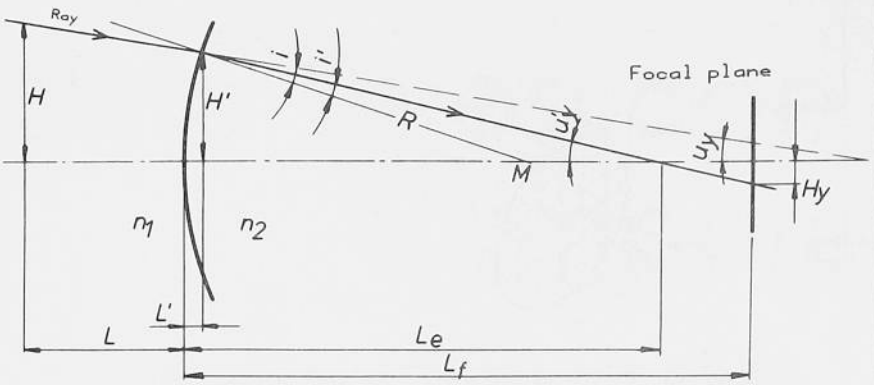


Fig. 3. Principle of the meridional ray-tracing.

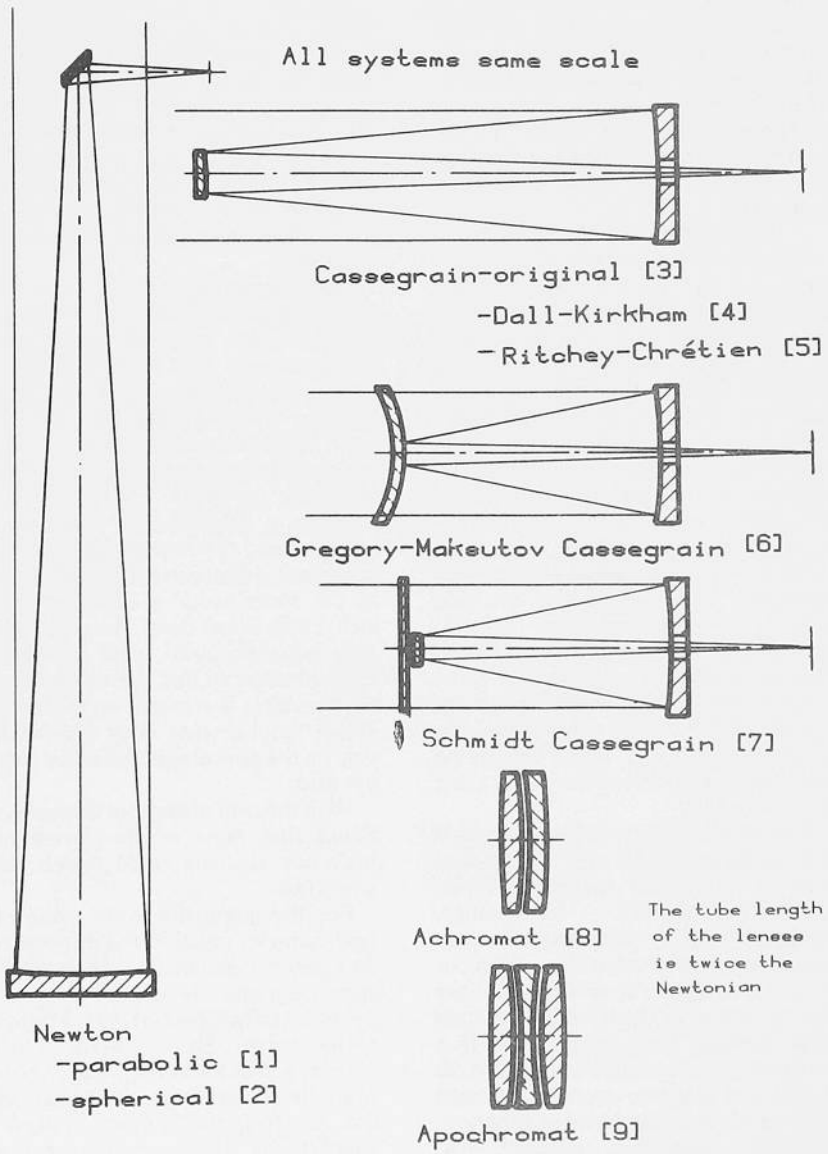


Fig. 4. The nine compared telescope systems.

On the basis of the above mentioned criteria, various systems can be compared and judged with respect to their principal suitability for visual and photographic use.

The Nine Systems

Among the many optical systems possible, we chose nine of special interest for the amateur. Figure 4 shows a sketch of these telescopes, and basic optical data on each are given in the tables.

For the first comparison pair, shown in Figure 5, we chose the following:

1. Newtonian telescope with an aperture of 150mm, a focal ratio of f/8, with a paraboloidal primary.
2. Newtonian telescope with an aperture of 150mm, a focal ratio of f/8, and a spherical mirror.

For the second comparison, Figure 6, we chose three systems, all having an aperture of 150mm and a focal ratio of f/15. Note that the size of the Airy disk is greater with the longer focal ratio. These systems are:

3. Classical Cassegrain, parabolic primary mirror and hyperbolic secondary.
4. Dall-Kirkham Cassegrain, elliptical primary mirror and spherical secondary.
5. Ritchey-Chretien Cassegrain, hyperbolic primary mirror and hyperbolic secondary.

For the third comparison, Figure 7, we chose:

6. Maksutov-Gregory Cassegrain, very slightly aspheric primary mirror, spherical meniscus corrector shell, with aluminized spot on its back side as secondary mirror.
7. Schmidt-Cassegrain, spherical primary mirror, elliptical secondary, and Schmidt corrector.

For the final comparison, Figure 8, we chose two refractor designs and ray-traced each in three colors with wavelengths of 657.27, 587.56, and 486.13 nanometers:

8. Achromatic refractor with two lenses.
9. Apochromatic refractor objective with three lenses and three glass types.

Figures 5 through 9 show a direct comparison between the various spot-diagrams, a 0.025mm (0.001 inch) circle, and the Airy disk. The Airy disk circle has a diameter of 0.011mm for the Newtonians, and 0.020mm for the f/15 telescopes. These diameters refer to yellow light with a wavelength of 587.56 nanometers.

Results

Always mind the scale when comparing the spot-diagrams. This scale could not be kept the same for all figures. From Figure 5, the convergence of rays of the parabolic mirror on the optical axis in the focal plane is perfect. This, of

course, can also easily be proven without calculating spot-diagrams!

The convergence of rays for a spherical mirror on axis, however, even at the optimum focal distance, leaves much to be desired. As a result of spherical aberration, the spot diagram is enlarged, and is not sufficient for visual use. It can be proven, by moving the focal plane, that the minimum spread in the spot-diagram will be achieved when the focal distance is not 1200 but 1199.5mm. The sharpness for photographic use will then be just sufficient. Off-axis, both systems have an asymetrical figure, the so-called coma figure. According to Seidel theory, coma will increase proportionally with the distance to the axis, and astigmatism with the square of this distance. With the spot-diagrams, it is possible to judge the worsening of the optical quality of the Newtonian for increasing distances to the axis. For both mirrors, the size of the photographically useful field appears to be roughly the same, and is restricted to a distance of approximately 14mm from the optical axis, if the criterion of a 0.025mm diameter spot is employed.

The comparison of systems 3 through 9 is much more interesting: on the one hand, because they are all compound systems, on the other, because in two of them — the refractors — chromatic aberration plays a significant role.

The position of the focal plane was chosen so that the spread of the spots on the optical axis is minimal for yellow light.

Let us compare the performance of the five Cassegrain systems (numbers 3 through 7), in Figures 6 and 7. As you can see, on the optical axis, a very good convergence of rays can be obtained. The primary mirror of the Gregory-Maksutov Cassegrain needs a slight local aspheric figuring. Without this figuring, the spot-diagram on the axis would have a diameter of 0.068mm and this aberration would also be active outside the optical axis. The color aberration in catadioptrics appears to be very small, so Figure 7 gives only results for yellow light.

In judging the five Cassegrain systems for photographic use, the following should be kept in mind (a fact that is unknown to many users of these instruments!): the image plane of these instruments is forward curving as a result of the strongly curved secondary mirror. Because the film is flat, unsharpness will occur off the optical axis. The spread of the spots in the spot-diagram is larger compared to a case where the film is bent to the same radius as the focal plane itself.

In most of the five telescopes, the degradation of the off-axis photographic image sharpness as a result of the curvature of field is much larger than the

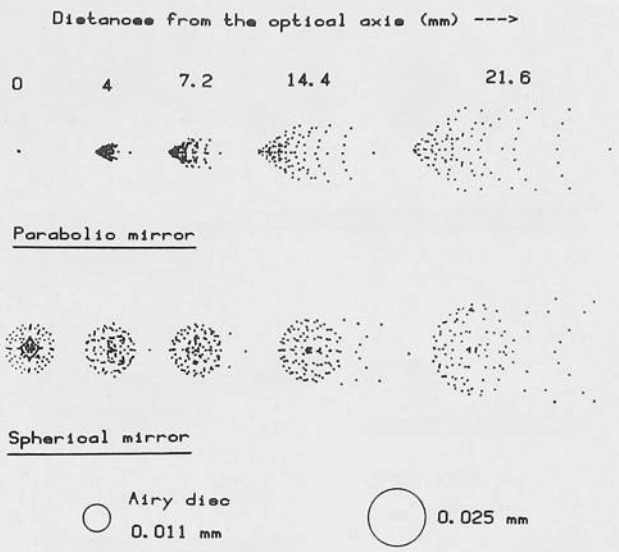


Fig. 5. Spot diagrams of the Newton telescopes with optimal focussing on the optical axes. D=150/F=1200 mm.

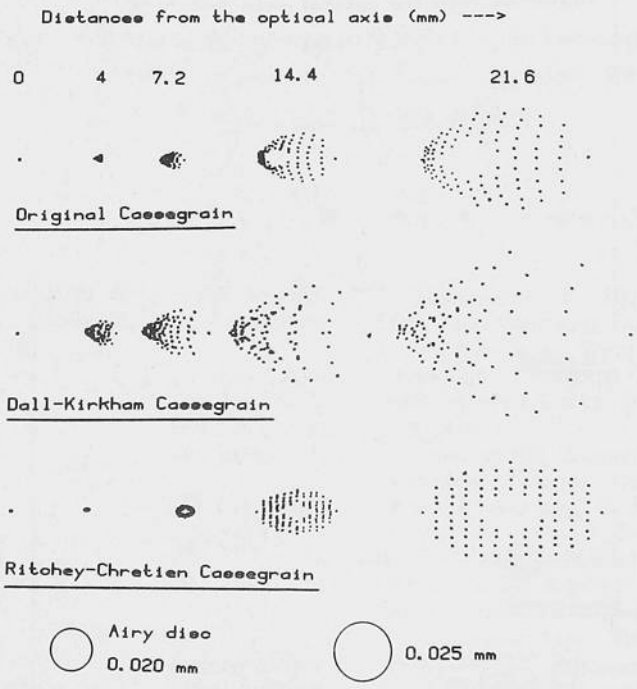


Fig. 6. Spot diagrams of the Cassegrain telescopes. D=150/F=2250 mm.

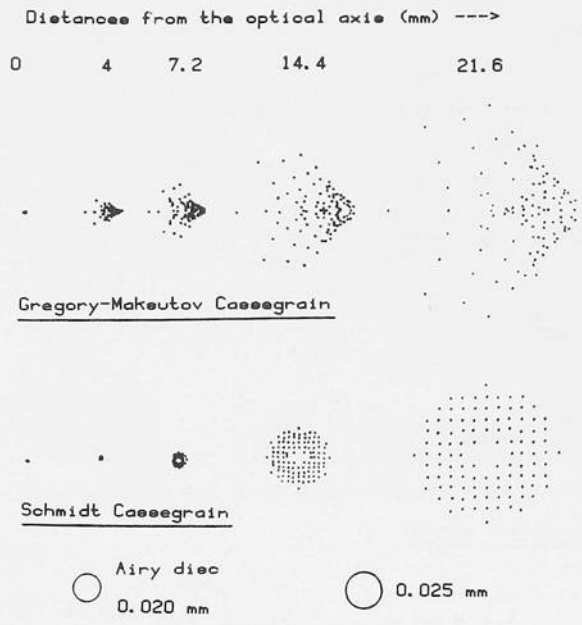


Fig. 7. Spot diagrams of the Gregory-Maksutov Cassegrain and the Schmidt Cassegrain. D=150/F=2250 mm.

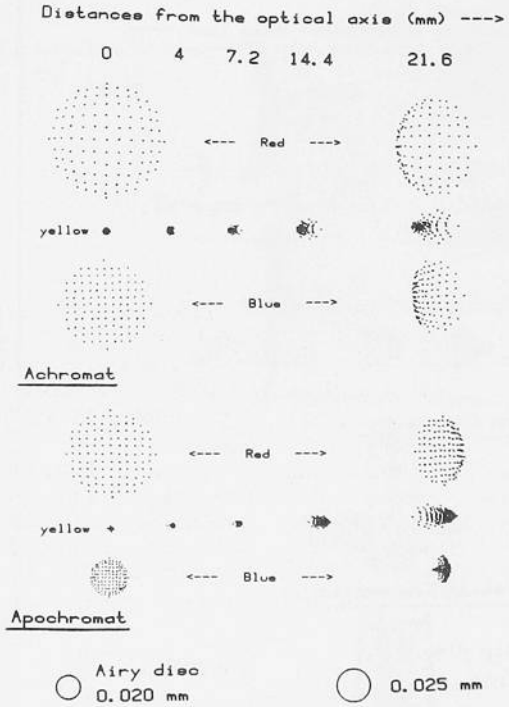


Fig. 8. Spot diagrams of the lens telescopes. D=150/F=2250 mm.

Table 1. Optical characteristics for the five cassegrain-

	original
Radius of curvature primary mirror	- 1500.00
Deformation	- 1
Radius of curvature secondary mirror	- 686.25
Deformation	- 4
Distance between mirrors	521.25
Focal distance from secondary mirror	686.25
Radius of curvature from surface corrector	
Back surface corrector	
Thickness corrector	
Distance corrector - primary mirror	
Kind of glass corrector	

* The primary mirror of the Gregory-Maksutov cassegra one fourth of a wave length.
** The back side of the Schmidt corrector has a Schmid corrector for a mirror with focal length 367.67 mm a

degradation due to coma and astigmatism. Note that the curvature of field in the three true Cassegrain systems (3, 4, and 5) is smaller than in the catadioptric systems (6 and 7). This is not a general rule, but it is a result of our choice of curvature of the primary and secondary mirrors, and the associated so-called secondary magnification. For reasons of practicability, we chose a smaller secondary magnification for them (roughly 3, as it is usual for these systems) than for the catadioptric systems (roughly 6, also usual for these systems).

The choice of secondary magnification also influences rather strongly the size of the instrument, as shown in Figure 4, where the systems are drawn at the same scale. In order to illustrate how the off-axis sharpness can be improved when a curved film is used, Figure 9 compares spot-diagrams for systems 3 through 7 in the extreme corner of the 24 x 36mm negative.

It is assumed here that the curvature

Table 2. Optical characteristics of the lens objectives for D = 150 mm and F = 2250 mm (dimension mm)

	Achromat	Apochromat
Radius of curvature first lens surface	1507.315	2223.689
Axial thickness first lens	23.502	29.934
Radius of curvature second lens surface	- 732.184	- 697.716
First axial distance	2.486	0.293
Radius of curvature third lens surface	- 738.968	- 697.716
Axial thickness second lens	18.832	19.131
Radius of curvature fourth lens surface	- 2727.629	555.922
Second axial distance		4.726
Radius of curvature fifth lens surface		560.424
Axial thickness third lens		29.934
Radius of curvature sixth lens surface		- 1809.560
Focal distance	2226.09	2262.66
Kinds of glass 1 - 2 - 3	BK 7 - F 3	PSK 3 - SF 4 - SF 11

ke systems under consideration for D = 150 mm F = 2250 mm

Dall-Kirkham	Ritchey-Chrétien	Gregory Maksutov	Schmidt
- 1500.00	- 1500.00	- 735.34	- 735.34
- 0.63852	- 1.0975	approx. 0[a]	0
- 686.25	- 686.25	- 172.20	- 173.96
0	- 5.0791	0	- 0.54
521.25	521.25	302.74	293.69
686.25	686.25	463.6	445.44
		- 164.56	flat
		- 172.20	see [a]
		13.01	6.88
		302.74	315.35
		BK 7	BK 7

has a very weak aspherical retouche of approximately

like deformation. The power is 84.5% of the Schmidt
d an aperture of 150 mm.

of the film is exactly matched to the field curvature of each of the telescopes. The Schmidt-Cassegrain is diffraction-limited over the whole curved focal surface and performs best of all investigated Cassegrain systems. This is a confirmation of Ronald Willey's result in his article in *Sky and Telescope* in April 1962. However, unless compensated by field flattening devices, the Cassegrain-type systems all have a rather small photographically useful field.

Comparing the refracting telescopes (systems 8 and 9) in Figure 8, it appears that the color aberration can not be supressed sufficiently. The large spread of spots for red and blue are rather impressive in the achromat, when this system is in focus for yellow. For the apochromat, the color aberration is smaller than in the achromat, but still clearly present. As a consequence, both telescopes will have color fringes when bright objects, such as the Moon and planets, are observed. The other monochromatic aberrations are much less present in the lens telescopes than in the mirror and catadioptric systems, which we discussed before. This phenomenon is a result of the less strongly curved surfaces, particularly the differences in curvature, for the lens telescopes. This is clear from the spot-diagrams at a distance of 21.6mm from the axis for yellow light that the spot diagram for that color meets the photographic criterion of 0.025mm.

Entrance Pupil Obstruction

Ray-tracing does not take into account the diffraction effects caused by the central obstruction in reflecting telescopes. Apart from a loss of light, these obstructions cause a lowered image contrast which will be noticeable when these obstructions are larger than approximately 25% of the diameter of the entrace pupil. This diffraction effect does not play a part when the instrument is used for celestial photography, because the effect is below the limit of resolution of most films.

Fig. 9. Spot diagrams of the five Cassegrain telescopes at 21.6 mm (corner 24x36) on the curved focal plane.

H.G.J. Rutten
Boerenweg 32
5944 EK Arcen
The Netherlands
and
M.A.M. van Venrooij
Beneluxlaan 74
6164 ET Geleen
The Netherlands

References

1. *Die Fernrohre und Entfernungsmesser*, A. Konig and H. Kohler, Springer Verlag, 1959.
2. "Third-Order Aberrations in Cassegrain-type Telescopes and Correction in Servo-stabilized Images," M. Bottema and R. Woodruff, *Applied Optics*, Vol 10, No. 2, Feb. 1971.
3. *Spiegeloptik*, K. Wenske, Verlag Sterne und Weltraum, Dusseldorf.
4. "A Family of Compact Schmidt-Cassegrain Telescope Designs," R. Sigler, *Applied Optics*, Vol. 13, No. 8, Aug. 1974.
5. "Compound Schmidt-Cassegrain Telescope Designs with Non-zero Petzval Curvatures," R. Sigler, *Applied Optics*, Vol. 14, No. 9, Sept. 1975.
6. "A Cassegrain-Maksutov Telescope Design for the Amateur," J. Gregory, *Sky and Telescope*, March 1957.
7. "Cassegrain-type Telescopes," R. Willey, *Sky and Telescope*, April 1962.
8. "Characteristics and Testing of Cassegrain-type Telescopes," R. Willey, *Sky and Telescope*, April 1962.
9. "Transfer Functions for an Annular Aperature," Edward L. O'Neill, *Journal of the Optical Society of America*, Vol. 46, No. 4, page 285.

Pyrex Honeycomb Mirrors

– or –

how to build a large mirror blank in your garage

By using a lightweight mirror building technique originally formulated 60 years ago by Dr. G.W. Ritchey[1,2], we have taken the first step toward producing 0.5 to 7 meter astronomical mirror blanks at low cost. Honeycomb mirror technology is well known in space applications where weight is of utmost importance. Mirrors for use in space must be made of near zero expansion materials such as ULE fused silica, Cervit, Zerodur, etc., because they must produce diffraction limited optical images under extreme temperature conditions.

However, we believe that ordinary Pyrex or Tempax borosilicate, used in this type of lightweight mirror, can result in significant savings of cost and weight for groundbased telecopes of all sizes. Using a Pyrex-structured mirror allows the factor of five weight reduction obtained with Space Telescope-type mirrors while avoiding the high costs associated with the raw material and processing costs of the more exotic fused silica and glass-ceramic zero-expansion materials.

Furthermore, honeycomb mirrors may offer both a cost savings and improved image quality when compared to conventional solid mirrors. Cellular mirrors can maintain the rigidity of a solid blank while weighing only one-fourth as much. In addition, a lightweight mirror can be supported with a lightweight tube and mount so that all parts of the telescope are lighter and less expensive. Lightweight mirrors and mounts have shorter thermal time constants, since the thermal equilibration time constant varies inversely as the square of the thickness of glass. This means the mirror will come into equilibrium with the ambient air temperature faster during both optical testing and observing. This should result in better images since thermal figure changes can be severe as the night air cools the mirror from its daytime temperature.

The lower thermal inertia of the lightweight mirror can also contribute to better images. The current wisdom is that image quality in large telescopes can be significantly degraded by "local" seeing effects — warm air trapped in the dome or convection currents rising from a still-warm primary mirror. Pockets of rising warm air have a different density and refractive index than cool air so they bend the light rays entering the telescope. With a primary mirror at the ambient air temperature, the local seeing effects may be reduced.

Since lightweight primary mirrors are hollow, they can be actively ventilated with outside air, possibly allowing sub-arcsecond seeing to be achieved routinely with large telescopes at good sites. Lightweight primaries may also yield significant improvements in the images in large amateur telescopes.

All astronomers would like to have their telescope mirrors made of zero expansion materials to eliminate thermally induced figure changes. However, the price of these materials is, in many cases, prohibitive. Pyrex or Tempax is often chosen as a less expensive alternative which still has an expansion coefficient much less than ordinary glass. Many large telescopes have primary mirrors made of Pyrex, most of them cast with thick rib structures to help reduce weight and thermal problems. These include the 5-meter Hale telescope, the Lick 3-meter and the KPNO 2.1-meter. These telescopes perform as well as those with zero expansion primaries because of the large thermal inertia of all the solid blanks.

The UAO/SAO Multiple Mirror Telescope is the only large telescope presently using fused silica honeycomb mirrors. The MMT has reported excellent seeing which may be at least partly due to its low thermal inertia mirrors.

Ritchey constructed his mirrors by carefully grinding all the pieces to the proper dimensions, including curves in the ribs to match the curvature of the faceplate. These pieces were then glued together with thin layers of glue. Glue possesses the disadvantage that it may stretch or bend with time, causing loss of optical figure. In spite of this problem, Ritchey's 60″ mirror held together for several years.

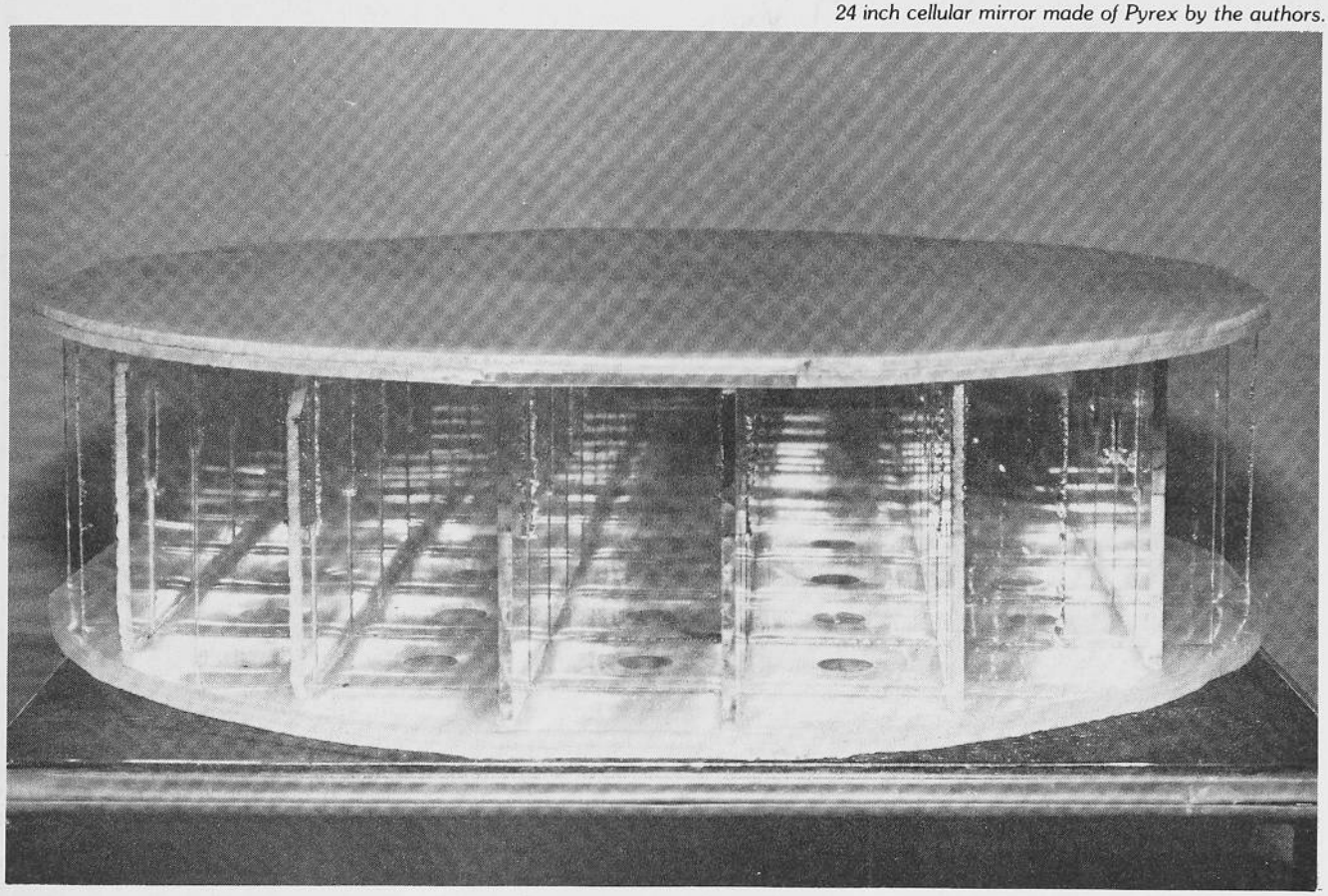
Honeycomb mirror structures can also be machined from solid pieces of glass or fused together from thin plates cut to the proper size. Pieces for mirrors of zero expansion materials must be carefully ground to the proper shape before the honeycomb is fused or welded together and the faceplates are fused on.

Fused silica mirrors fuse at 1600°C, a temperature where radiative transport of heat is very efficient. Since there is no possibility of establishing a thermal gradient, both faceplates must be fused onto the honeycomb structure at the same time. Paul Jones, of Star Instruments in Flagstaff, AZ, has used this technique to fabricate honeycomb mirrors from Pyrex.

We have avoided these labor intensive processes or precision grinding and welding by taking advantage of the lower softening point of Pyrex (821°C instead of 1580°C for fused silica). If the joints are heated while keeping the body of the structure cooler, the edges will flow slightly and form a solid bond at the joints where the glass has become sticky. This allows us to use pieces cut to the approximate shape with a diamond saw rather than precision ground joints since the soft glass will fill up any gaps in the edges to be bonded.

The only disadvantage of this bonding method is the formation of small negative fillets at the T-joints where the ribs sink

24 inch cellular mirror made of Pyrex by the authors.



into the faceplates. This would weaken the structure if it were subjected to significant shear forces.

Our first mirror, a 60cm f/4 sphere, used 12mm thick faceplates made by bonding two 6mm Pyrex plates together in the oven described below. Due to problems with residual bubbles trapped between the plates, future mirrors will probably have the faceplates made from a single layer of thicker plate material. Since Pyrex plate has a limited available width, mirrors larger than 1.2 meters must be made with several sheets fused together at the edges.

Between the faceplates, we have placed a honeycomb or eggcrate type structure. This consists of 140mm wide by 6mm thick plates arranged in an interlocking rectangular lattice with 90mm square cells. Each of the ribs had 8mm wide slots to accommodate the intersecting ribs.

The ribs were only bonded to the faceplate —and not to each other — since most of the stiffness comes from the I-beamlike cross section formed by the ribs and the faceplates. Each of the ribs had a curve cut in the upper edge to approximately match the front faceplate which was heated and preslumped to an f/4 curve. For small mirrors slower than f/7, it may be easier to make both sides flat or slump the blank after it has been fused together. After the pieces have been put together, we heated the blank one side at a time to fuse the ribs to the hot faceplate without collapsing the entire structure. The finished mirror must be cooled carefully to avoid cracking.

The Construction Process

After obtaining the glass, it must be cut into the shapes required to construct the cellular structure. Straight cuts and gentle curves can be made with an ordinary glass cutter. Pyrex is harder than window glass, so heavy pressure on the cutter is needed. We cut the slots in the ribs with a diamond-impregnated saw blade. We had the advantage of a large diamond bandsaw at Kitt Peak National Observatory, but amateurs could obtain the same results with a small circular saw available at the local "rock shop" for about $50.

The cutting process must be lubricated and cooled with Almag oil or water to avoid damage to the glass and saw. Be ready for a large mess! We recommend working outdoors for the cutting process. Practice on window glass is also advisable before starting in on the more expensive Pyrex.

The basic components of the oven are heating elements, lightweight insulating

Parameter Comparison of Glasses

Type	Expansion Coefficient	Anneal Pt.	Softening Pt.	$/lb
Fused Silica	5.5x10 $^{-7}$/°C	1084° C	1580° C	50
Pyrex	32.5x10 $^{-7}$/°C	560° C	821° C	1.5
Plate Glass	93.x10 $^{-7}$/°C	514° C	696° C	0.5

firebricks, and ceramic fiberboards or blanket for the lid. All of these seemingly exotic materials can be obtained for surprisingly little money at your local potter's store or brickyard, since potters routinely build kilns that operate several hundred degrees hotter than the temperature needed to make a mirror.

The oven consists of a bottom layer of bricks with grooves for the heating elements. The bricks are easily cut and grooved with a hacksaw, masonry drill bit, or carbide router bit. The heating elements are Fe-Cr-Al alloy wire, which we wound into a coil on a lathe and then stretched out like a sprung screendoor spring. This wire is made by Hoskins and by Kanthal, and is available at the potter's store. SiC heater rods can also be used. The control of the heater power can be as crude or sophisticated as you like. We're presently using a large relay controlled with a thermocouple-based oven controller, and a 555 IC timer for adjustable duty cycle.

We seem to get the best results with about 5 kilowatts of power per square foot of mirror. Since this power is only used intermittently, the total cost of electric power for a 60cm mirror is about $5. Additional details on building electric ovens and kilns can be found in references 3 and 4.

Just above, but not touching the heating elements, we placed a 4 cm-thick graphite plate for the glass to rest on. We chose graphite because it is a good conductor of heat and the glass won't stick to it. The graphite should completely cover the heating elements to prevent heat from rising around the edge by convection. Support this plate with posts cut from firebricks.

Graphite is easily machinable and was made with an f/4 convex curve for forming the front faceplate of the mirror. We used a flat piece for fusing the backplate. The only problem with graphite is that it tends to oxidize, or "evaporate," when exposed to air at 900°C. It is the most expensive piece of the whole oven, and may be difficult for the ATM to acquire. Possible alternatives to graphite include:

1) high temperature stainless steel, which is also expensive;

2) silicon carbide shelves, which are very oxidation resistant and somewhat cheaper, but not machinable; and

3) castable ceramic mixes which are cheap but not very good conductors of heat.

Materials other than graphite must be coated with graphite powder, silica powder, or ceramic paper to avoid the glass sticking to the baseplate.

The top portion of the oven is made with insulating firebricks and a ceramic fiber black roof. The temperature is monitored with 2 thermocouples: one in the graphite and one in the air near the mirror.

Our oven is not the definitive design. It works fine, but many improvements are possible depending on the type and size of mirror being made. Be creative in using available materials and be careful with the electricity or gas used for heating.

The Fusing Process

Here is the process we used to make a 60 cm mirror. First, the two faceplates were fused together by laying the appropriate pieces on the graphite and heating the oven to 850°C. Then the oven was covered and allowed to cool. We initially fused two square sheets and cut them into circles later. The front faceplate was first fused on a flat sheet of graphite, then slumped on a graphite dome at about 830°C. After the faceplates were made and cooled, the eggcrate lattice was assembled on the back faceplate on the graphite slab.

This lattice is self-supporting even before bonding. The trick in fusing the lattice on to the faceplate is to heat the graphite in order to heat the glass. We heated the faceplate to a bonding temperature of 880°C while keeping the lattice at 600°C to prevent it from collapsing under its own weight as the glass softened. This is the step that requires the baseplate of the oven to be a good heat conductor.

Any parts of the graphite not covered with glass were covered with insulation to prevent excess heating of the upper part of the oven. This insulation was butted up against the soft faceplate to prevent its edge from flowing. The top of the oven was opened to the outside air to keep the lattice cool enough. With some practice, you will be able to look into the oven to observe if the ribs have bonded completely to the faceplate.

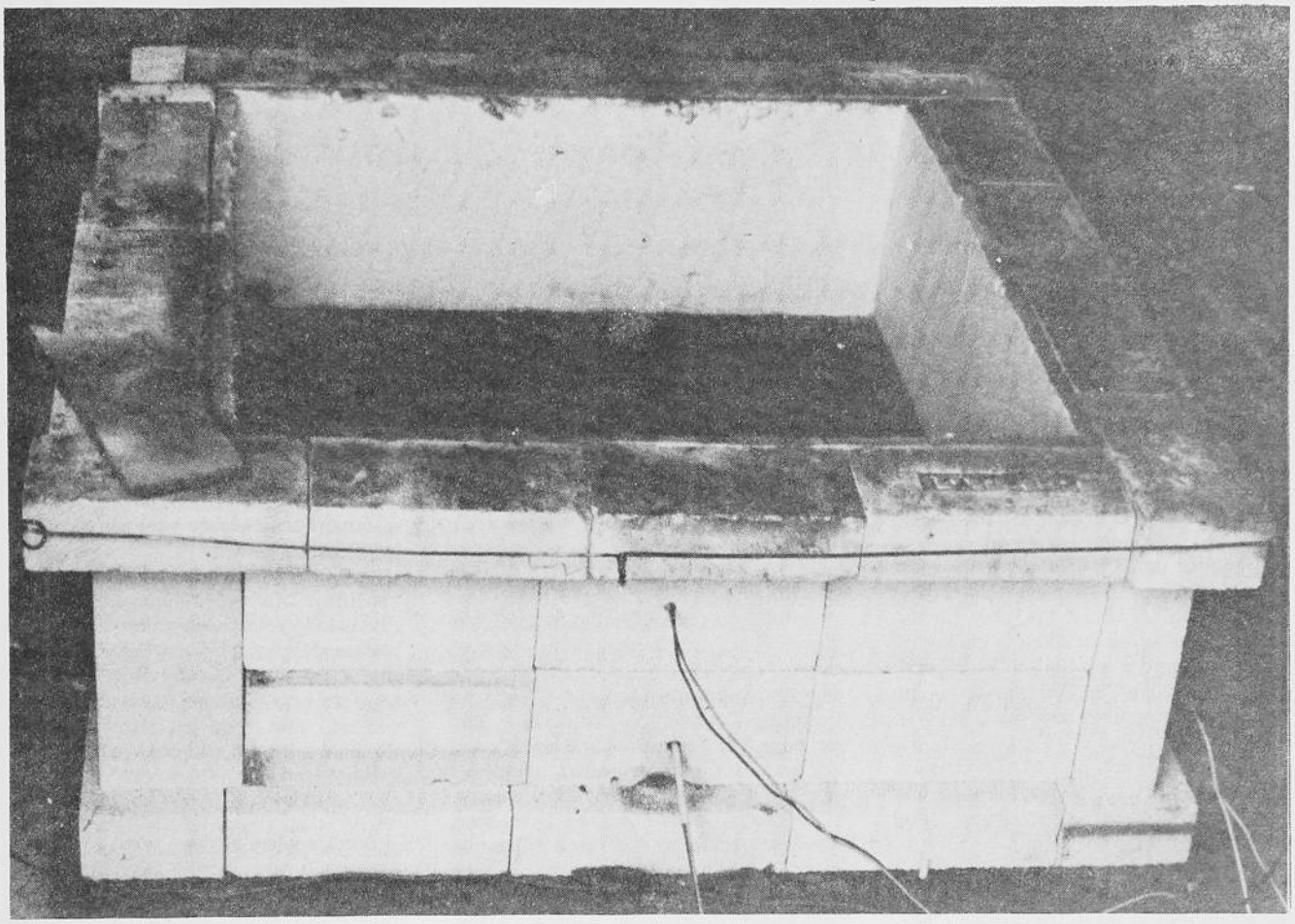
Keep a watchful eye on the ribs to be sure they don't begin to sag or lean from being too hot. We found the main lattice structure must be kept between 500°and 600°C. A note of caution: Be careful when looking into the oven! Eyes or skin should not be exposed to 800°C air.

After bonding, the entire oven was cooled to a uniform 600°C and covered with insulation, then allowed to cool. If the oven is insulated so the cooling is uniform and slower than 100°C per hour, the glass should anneal properly. If the mirror cools through the annealing range too rapidly, the internal strains will not be released and the mirror will crack into two or more pieces on cooling. You can then claim it as a new artform, since the cracks make very interesting patterns.

After the structure cooled, we removed it carefully from the oven. We turned it over, with the ribs down, onto the front faceplate on the domed graphite slab. We then repeated the previously described bonding cycle.

The backplate makes it more difficult to cool the lattice and avoid collapse while heating the front faceplate. Our

The original mirror making ove — crude but effective.



backplates had 2.5cm holes drilled in them to allow some ventilation of the cells. This may or may not be necessary to the process. After the finished blank had cooled, we removed it and prepared it for grinding and polishing.

We sent our 60cm blank to the University of Arizona Optical Sciences Center for grinding and polishing to a sphere. Of course, this is where the ATM gets really excited — at last, a large blank that he can lift without a crane. Ours weighs 50 lbs. The blank was polished to a ⅛-wave RMS sphere, although there is a large pit near one edge. The large cell width-to-faceplate thickness ratio allowed some "print-through" of the cell pattern onto the surface due to pressure of the polishing lap. To avoid this problem, we suspect faceplate thickness should be at least 1/6 the cell width.

After additional testing in our small oven, we have discovered that the easiest way to make faceplates for mirrors larger than 1.2m is to simply heat the glass to a liquid state at 1200°C. This allows us to make faceplates out of broken-up chunks of glass, i.e., kitchenware, etc. . . It may prove economical to make your own faceplates for smaller mirrors this way as well. Pursuing this avenue further, we are presently casting entire cellular mirrors by melting chunks of glass into a mold. We plan to have completed a 1.8m cellular mirror by the spring of 1982.

Dave Anderson and Gary Poczulp of Tucson have recently completed a lightweight fused mirror with approximately 100 sawn-off Pyrex tubes as the honeycomb structure. They intend to sell similar mirrors in the future. Paul Jones, of Star Instruments, is currently marketing Pyrex honeycomb mirrors and other types of lightweight blanks. Persons wishing to purchase lightweight blanks larger than 2 meters should contact the authors.

We would like to thank the staff of Steward Observatory, Optical Sciences Center and Kitt Peak National Observatory for their support and encouragement of this work. This project has been supported by NASA grant NAGW-121.

John M. Hill
J.R.P. Angel
Steward Observatory
University of Arizona
Tucson, AZ 85721

References

1. Ingalls, A.G., *Amateur Telescope Making Book 1*, page 320, Scientific American, Inc., New York, 1976 (4th ed.).
2. Ritchey, G.W., "The Development of Astrophotography and the Great Telescopes of the Future," Astronomical Society of France, 1929.
3. Colson, F.A., *Kiln Building with Space Age Materials*, Van Nostrand Reinhold Co., New York, 1979.
4. Fournier, R., *Electric Kiln Construction for Potters*, Van Nostrand Reinhold Co., New York, 1977.
5. Corning Glass Data Sheet

Commercial Telescopes: the view from the supply side

Why Commercial Companies Exist

When you buy a telescope, you expect to gain certain capabilities and satisfy certain needs. The same is true of any product you buy, whether it is a hamburger or an 8-inch telescope. The product has a certain utility for you. The expectation of utility is one of the foundations of all mankind's economic activity — and it is what motivates you. Providing utility is the reason some telescope companies succeed and some fail.

You see, the first goal of a company is to survive. If it is to survive, the company must understand and apply "The Marketing Principle."

Yuk! Marketing! Isn't that just fast talk and some salesman's claim that you'll be amazed with your purchase? No. Convincing you to do something is "Salesmanship" — and it can be tasteful, informative, and honest. Everybody does it to some extent in every phase and aspect of life. It's usually how you get and keep a job.

Marketing is very different. Marketing is the process whereby a company's management produces products that are matched to the needs of like-minded individuals, or a "market." Wait a minute now — I *didn't* say marketing is manufacturing, or the physical process of making something. Telescope marketing managers are not necessarily making telescopes because they love producing telescopes (however, many are — that's how I, and many others in professional manufacturing, got involved to begin with).

A company is really in business to satisfy a need, a demand that you, the customer, make. Once upon a time, refractors were in heavy demand. Now catadioptrics and reflectors are eagerly sought after. A company that is well-organized realizes that it is there to satisfy, and sometimes create or modify, the dreams and desires of people. The company must be oriented to the ideas that inspire people to act. In short, a company is there to service a need that's perceived by the public — and the company happens to be active in its field because of the interest in the subject, the technological capacity of its personnel and the perception of its management.

A company that makes telescopes shouldn't think of itself as a telescope company, but as an organization that satisfies the needs of people who are interested in astronomy. If you apply this idea, you'll realize the huge number of activities that are possible for a company that has the great joy of understanding astronomy, and that many types of products can be understood, created and produced to satisfy astronomy buffs. Such products are telescopes to see the sky, cameras and film to photograph the sky, slides and posters to proclaim your astronomical orientation to the world, and anything else that will satisfy the public's aggregate needs.

A long-lasting company must be customer-oriented — it must give you what you want — rather than devote itself to making a product. This is the real basis of marketing. Those companies that realize this are the ones that seize the opportunity to make a good product, satisfy the needs or desires of people, and create a market of CUSTOMERS.

They are also the organizations that survive and, perhaps, grow. Commercial companies that make telescopes (manufacturers) entered the field of astronomy materials because: 1) they have a unique ability (whether it's real or perceived) such as manufacturing, providing service or merchandising; 2) the management was smart enough to realize that an opportunity existed — that the company could exert its efforts to produce a good or service that people wanted, and this product could be transferred to people for a price so that the company could survive.

Astro Businesses

Now realize we've been discussing manufacturers mostly but a smaller business or a store can also satisfy customers. Many avenues are open to them — providing competent service, prompt service, making small and attractive packages of products, making small products that require little capital to organize production, or offering a product to a market segment where the product wasn't represented before (i.e., telescopes in a computer store or in an organization that caters to, say, physicians).

In the last 15 years, amateur astronomers have seen the selling of telescopes progress from backyard manufacturers peddling their story and product through mail-order, to a blossoming of organized manufacturers and organizations of hundreds of retail dealers. This is a natural, indeed classical, strategic plan for growth by thoughtful manufacturers.

Simultaneously, people have become

increasingly interested in astronomy for many reasons. Manufacturers capitalizing on this opportunity to grow developed telescopes for you — and the telescope dealers sprung up to satisfy your need for more astronomical outlets.

Manufacturers want dealers so that they can improve their customer service. In being served by a network of dealers, you, the customer, merely have to ramble down the street or into town to get help in using your new pride-and-joy. A local dealer can assist you in your instrument choice, accessory selection, and its proper use, simple troubleshooting, routine maintenance, or provide you with contacts to other people who enjoy astronomy as much as you. They might even be willing to start or provide space for an astronomy club to meet.

Many people, small entrepreneurs who combine the love of astronomy with the practical skill of running a retail business, saw the opportunity. Lots of them got into the telescope business. You, the slightly bewildered stargazer, now may decide from whom to buy a telescope. As you scan the pages of astronomical periodicals, you'll see ads from many telescope dealers (not themselves manufacturers) all saying they can be your best friend when it comes to buying a telescope.

Why the flurry of ads? It's simply competition. The astro-suppliers are battling each other to try and get a lion's share of the business in telescope sales. These dealers and several dozens who sell via mail order are trying to differentiate themselves from each other by a whole variety of means. How? They offer free accessories, unusual products, ultra-low prices or ultra-good service to set themselves apart from the crowd. Each is seeking a "competitive advantage."

You have to make the choice that is best for you. You might opt for low, low prices — but realize that the knowledgeable dealer ten miles away who charges slightly more could very well be a much better source of help as you try to figure out your new gizmo. You usually get what you pay for in the end — and a full service dealer who backs the product is usually well worth the price you pay. Remember, your local dealer has no responsibility to service your telescope or help you learn how to use it if you bought it from a mail-order firm in order to save a few bucks!

Paradise Lost

What many consumers don't recognize is that the dealers are independent businessmen. They are not clones or puppets of the manufacturers. You cannot expect all retail dealers to always behave with the same expediency that the manufacturer would like them to. My point? Simply do not expect a manufacturer to intervene if you have problems with a dealer. A manufacturer can only sympathize with you, give you the truth about the nature of the product, tell you what to expect from the product, tell you its stock situation, and honor an instrument warranty. But do not expect a manufacturer to force a mail-order dealer to deliver a telescope, or give you a service, or take back an instrument that you're not delighted with (especially after the instrument was knocked over, or after you've used it for 17 weeks).

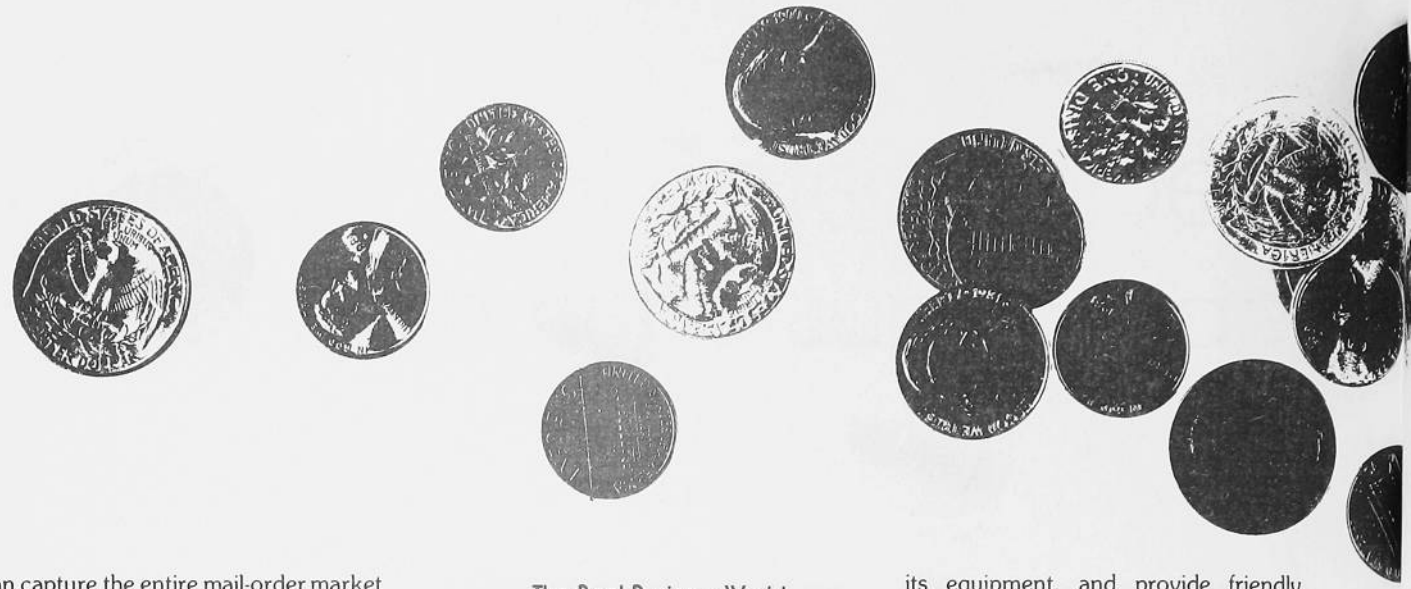
True, a manufacturer has to be alert to frequent complaints of this nature from particular dealers — if such behavior is frequently demonstrated by a dealer, then the manufacturer feels an ethical pressure to "drop" a dealer as a representative.

Mail-order firms and manufacturers have liability. Many are, indeed, reputable firms with good intentions. Some, due to poor management or understanding, simply cannot handle the workload or cannot deliver or make products that aren't what's advertised. Mail-order firms in general come and go for many reasons as do manufacturers who sell by mail.

The consumer who purchases a product, especially by mail, does have recourse if the product is not delivered or if the product is not of the quality represented. But note: You should contact the party you bought the product from directly — not the ultimate manufacturer — for immediate satisfaction. There are free legal services available to you: the local Better Business Bureau, the state attorney general, the postal authorities (but only if you purchased through the mail), state and local consumer protection agencies, and the Federal Trade Commission (FTC). As a last resort you can hire an attorney.

Dealer Misunderstanding

What telescope dealers fail to understand is that a manufacturer does not take on a dealership so that dealers



can capture the entire mail-order market — all those people who read the astronomy periodicals. Only the manufacturer has the expertise and budget to do that best. A dealership is a place for people to see a telescope and to get help in using them. In exchange for the chance to see and learn about the telescope, the consumer buys from a local dealer.

By having dealers throughout the country, a manufacturer displays his products to people who would never have bought without seeing the instrument first, a very important consideration for beginning amateurs or for people who enter from an allied field such as photography. Sure, the dealer wants to sell telescopes — and if the dealership is creative at promoting them, they will sell telescopes to people in all walks of life, expanding the number of stargazers in the world.

But a good dealer must be willing to do some work to successfully represent a company. The dealer and his customer service staff must take the time to learn about the product so that they can accurately represent the product to you, the public. A good dealership will make an effort to understand its public also; to anticipate what you, the public, wants to buy and how it should approach its promotional and product support efforts.

A dealership that is an astronomical manufacturer's dream would be one that supports the product, understands and explains the product, services the product, and via its own promotional efforts, gets more people to enter and enjoy amateur astronomy.

The Real Business World

Manufacturers want telescopes to be bought by all sorts of people. Why? For the same reason you go to work everyday — for a profit. Profit isn't a dirty word — it's what makes organized society flourish. Everybody who goes to work each day goes with the expectation of trading their labor for a profit, otherwise you'd do something else.

This is not to say that manufacturers and dealers aren't interested in astronomy. People start businesses because they are interested in the field, are adept at doing the job correctly and efficiently, and because they like to help people enjoy something that they enjoy. Astronomical manufacturers and dealers are very lucky people, indeed, to labor at something that they enjoy!

Along with the hope of profit, a manufacturer takes on a lot of social responsibilities when it enters into business. First, the product the manufacturer produces must satisfy consumers and live up to its advertising. The manufacturer also has to satisfy the people it does business with. The manufacturer has to pay its bills. If it doesn't, it can't get the materials or the tools it needs to build the telescope of your dreams — and then it has delivery problems.

It also has to pay its employees good wages — plus offer other benefits such as insurance and pension plans — to attract and keep top quality talent and to protect good equipment. All this takes capital. The manufacturer also has to support its equipment with proper instruction manuals, educate owners and dealers of its equipment, and provide friendly, efficient repair service.

Many small manufacturers of astronomical hardware enter such ventures because they are good at a manufacturing skill. However, this is not the only requirement of maintaining a business. As a business, you must respond to the changes of the market, you must satisfy customers, you must deliver when and what you promise, and you must pay your bills. All of these must be done if you are to survive.

All too often, this has not been understood, or has been realized too late, by small manufacturers and dealers. You, the astronomical public, have witnessed the coming and going of manufacturers and dealers. The major reasons an "astro business" fails are:

1) Undercapitalization. It costs a lot of money to run a manufacturing facility. Unless you have the backing to meet payroll, buy machinery, and survive economic fluctuations, your firm probably won't survive.

2) Failure to serve customers promptly and with courtesy. It's slow, but word-of-mouth anti-advertising gets around eventually.

3) Devotion to the product rather than adapting to the needs and buying power of the public who's buying the telescope (the marketing principle again).

So, a manufacturer can't always provide you with the custom scope of your dreams. Why? First, realize that everybody is slightly different, that you have specific projects and observations in mind that other people do not. So manufacturers attempt to produce a product, say a telescope, that will do

everything well.

For example, you know that a larger telescope can often show more detail and fainter stars and your interest is deep sky observing; so, why don't manufacturers make a cheap 74" telescope? Hey! Think about it; it would be pretty neat for deep sky observing, right? Yes, but there are problems. First, you won't find too many people who want to move that kind of instrument tonnage around. Second, how many could afford it (a more interesting question to telescope engineers is: Exactly how little could it cost?)? A large market does not exist for such giant scopes, although if they were made, some would be sold.

But the manufacturer must be concerned with how many it could sell. Why? Because the time and money that a manufacturer puts into a project is huge and, unless the manufacturer wants to throw its money away, it must invest in projects that will succeed. Indeed, one project to make a small 65mm diameter spotting scope required an initial investment of over $100,000 for tooling, not to mention the cost to assemble, design or produce them!

You can see why it's a little ridiculous to expect a large manufacturer to custom-tailor its specifications exactly to your needs — it simply costs much more than you'd be willing to pay. If you need a special feature or just want it done such and such a way, you are invited to join the ranks of the ATMs — Amateur Telescope Makers — and build it yourself. Custom instruments can be made by people who do prototype work, but the cost for their engineering, design skill and craftsmanship isn't something to pass over lightly.

Manufacturers attempt to provide good products with the standard features or accessories that people desire most. True, you may not always want such-and-such a feature, but if the manufacturer doesn't serve the needs of the majority of telescope buyers, the marketing principle enters — and the manufacturer has real troubles.

Still, you may really want a certain little feature, and that's what accessories and dealers are for — to customize your telescope to your exact desires — and also why you should write to manufacturers and let them know what changes you want.

One last thought on delivery. When you've decided that you want a telescope or accessory after you've just read the ad, you want it — right away! If the promise of what it can do is postponed, you'll get upset. Sometimes a delay is unavoidable — even though the manufacturer is doing everything possible to produce the instrument as fast as it can and still do a good job.

Delays by suppliers and subcontractors, machinery breakdowns, the illness of key employees, and a hundred other reasons can delay production. Believe me, it doesn't help a corporate image to advertise a product and not have it in stock, but no business wants to have a warehouse full of a product with the national advertising not coming out for two months!

So there is a pressure to get advertising out, and since advertising is a lot easier to produce and schedule than making a telescope, sometimes there's a shipping delay. A reputable manufacturer will let you know if a delay is anticipated, and its customer service/order processing should give you honest information.

However a manufacturer can't tell you, unless there is a backorder situation, why a dealer hasn't delivered. The manufacturer doesn't know when you placed the order, when the dealer placed the order (if they did), which of the dealer's orders is yours, etc. It happens to be a very convenient excuse for a dealer to blame the factory's inability to deliver as the reason you're not getting your telescope. Sometimes it's true. Very often, however, it is the dealer's inability to pay, or forgetting to order on time, or other quirks of human nature that have caused the delay.

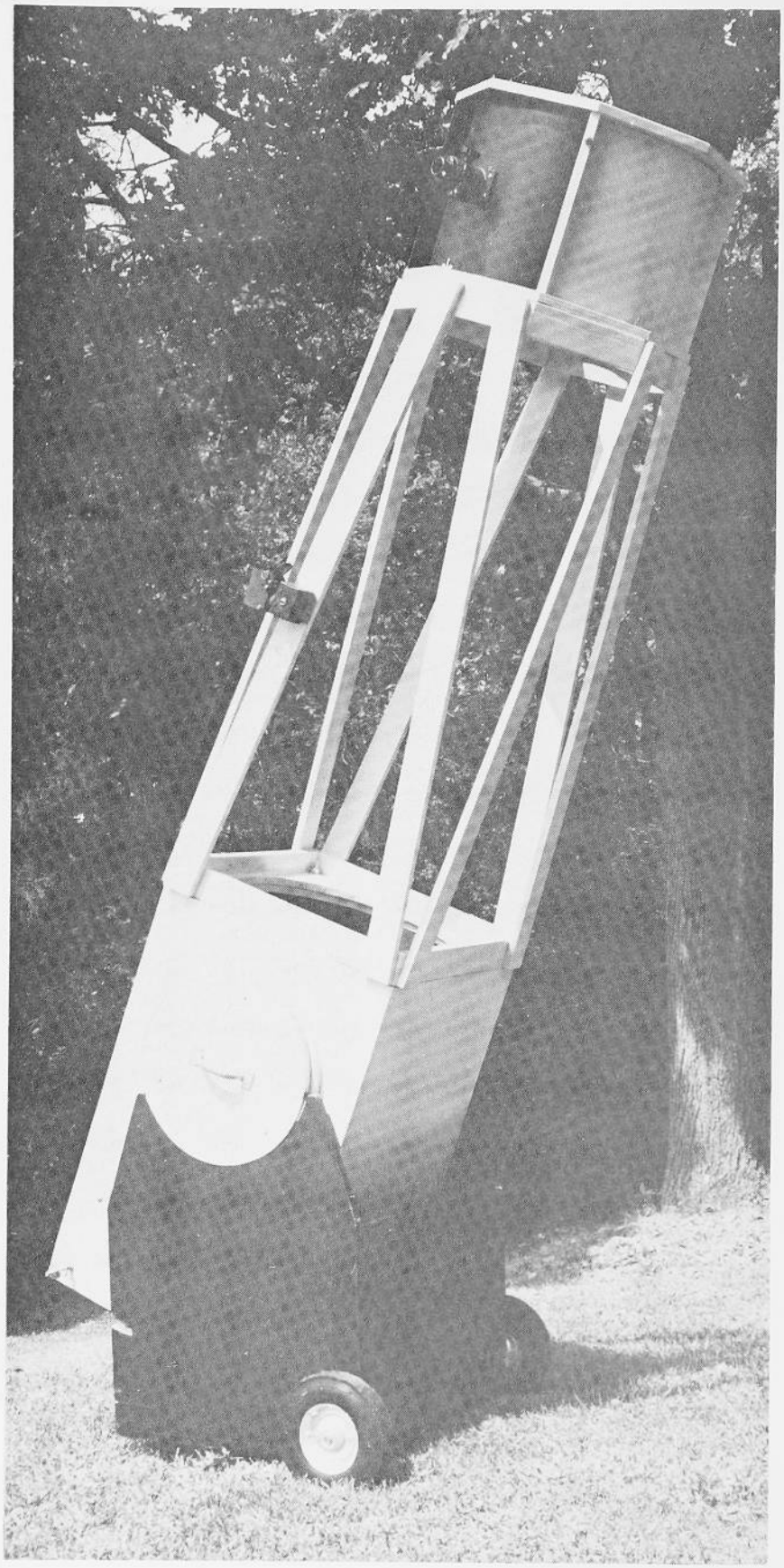
Be persistent and try to work with the dealer; honest, service-oriented people at a dealership will do everything they can to get you your telescope and keep you advised. Realize that a mail-order firm must give you the option of refunding your money if the delay is going to be longer than 30 days.

Kevin Ritschel
Manager Consumer Sales
and Technical and
Astronomical Services
Celestron International
Torrance, CA 90503

Editor's Note: The more the customer knows about the telescope business, the happier he'll be in ordering a telescope.

— RLB

A 20" Thin Mirror Dobsonian



Surely we all dream of building a 20" telescope. Having built telescopes over many years, including five 12.5-inchers, I decided to go for the big one. Finding no adequate mirror blanks, I called the Corning Glass Works. They referred me to their local dealer who cut a blank of 7740 Pyrex glass, 1¼" thick, 20" diameter, with polished plano-plano surfaces.

Since the telescope was to be portable so that I might escape the lights of Greater Cincinnati, I decided to build a Newtonian with a Dobsonian mount. The telescope will eventually be mounted in an English yoke mount inside my observatory. When that is built, the Dobsonian mount will then be used for taking the telescope to dark sky sites. Since I plan to do prime focus photography with this telescope, I chose a focal ratio of 5.6 so that a 35mm film format would have sharp images over the whole photographic field.

Grinding the Mirror

All rough grinding was done on my Elgin four-spindle grinding machine with #45 silicon carbide grit. The tool was a 12.5" Pyrex mirror blank. I spent 40 hours rough and fine-grinding the mirror on the machine, only to discover after a flash polish that the mirror was severely warped and that there were three large low pockets on the surface. The major cause was the ¾" plywood holder for the mirror which was flexing during grinding allowing the tool to rotate erratically. The small tool made matters worse. It was clear that the mirror needed a rigid support and the lapping machine was causing part of the problem, so I went to handworking.

I bought two patio stones, one 18" and the other 24" in diameter, and a box of latex concrete. I mixed and poured a batch of concrete on the 24" stone, pressed the mirror back onto it and worked it back and forth to flatten the concrete. I let the mirror set on top for most of the drying time so there would be good conformity to the mirror back. The pad ended up about ½" thick. I placed the 24" stone on a 55 gallon drum filled with water for support during regrinding.

I placed five layers of wet newspapers on top of the latex concrete pad, which acted as a cushion between the stone and glass. The mirror was placed on the newspapers ready for regrinding with 30 micron grit. The mirror was held from

sliding around on the stone by three cleats, using half a wooden clothespin as a wedge on one of the cleats.

As soon as regrinding started, the low pockets and low edges showed up. The 12.5″ tool worked well in this manner but a larger one would have been better. Grinding continued until the surface was completely ground in, using the pencil test, then on to the remaining grits. After a brief polish, the mirror showed the same shape only to a much lesser degree. I repeated the process again, with still better results, and decided that the remaining defects would be removed in polishing. This was a serious mistake and one that I would pay for over the next month. A good rule of thumb is to always remove grinding defects in the grinding stage.

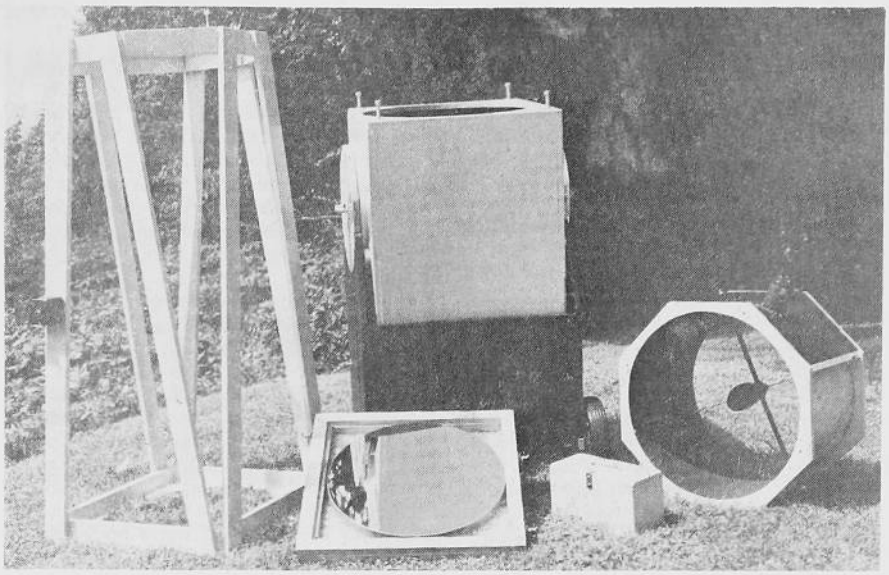
Polishing and Figuring

After polishing with the 12.5″ lap for a couple of evenings, I decided that I was getting nowhere fast. The polishing was extremely slow and the astigmatism was not improving. I poured a batch of latex concrete on the 18″ diameter patio stone, placed a green garbage bag over it, and pressed the mirror's curved surface on it. I worked the mirror back and forth on the concrete to form a matching curve. After drying, I sealed the form with spar varnish and then poured a lap on it. I had just enough pitch to cover the lap. Since the pitch layer was going to be thin and faster polishing was wanted, I kept the pitch a little on the soft side.

The lap worked well, although I had to press and rechannel often. The drag was very high and every polishing session was an excellent workout for me. Working the mirror on top of the 18″ lap quickly polished the central part of the mirror. Gradually the complete polish worked toward the edge, and at the same time the astigmatism was vanishing too. When the mirror was completely polished, as determined by imaging a very strong light on the mirror surface with a 25mm eyepiece, figuring began.

When the approximate depth was reached for the parabola, the doughnut shadow had some out-of-round irregularities in it and the outer 2″ of the mirror still had some remaining astigmatism. The more I polished with the 18″ lap, the better the figure looked. When I overcorrected, made the parabola too deep, I worked the 12.5″ lap on top to flatten the curve.

Testing was done using a Couder mask as described by Jean Texereau in his book, *How to Make a Telescope*. My mask had seven zones. Each test comprised of testing the figure for all seven zones with each quadrant of the mirror at the top during testing — or 28 readings for each test. In this manner, the exact shape of the surface became known and was corrected accordingly using accented pressure on the high spots. After the mirror was finished, it checked at 1/20th wave and my notebook had pages and pages of numbers filled in from the many tests.



At this time the telescope was not yet built, so star testing was not possible to check the cell and support system — another mistake, since the support system for the thin mirror is just as important as the mirror itself. Final testing must be done using this support system.

Building the Telescope

A year went by before I had time to build the telescope. Plywood is the main building material, the base sections using three layers glued together. The bearing circles are 14″ in diameter and have aluminum strips running around the periphery that slide on the Teflon blocks.

Since I intend to mount the telescope equatorially, the mirror cell is not the typical Dobsonian design incorporating a belt. The cell is a large 20″ diameter disk made of two layers of ¾″ plywood glued together with a masonite rim to hold the mirror from sliding sideways. On top of the wood is a layer of "bubble pack," a common shipping material which takes up any small irregularities between the mirror and the backplate of plywood.

This cell worked very well at first, until the wood warped, then I had severe astigmatism in the images. After reinforcing the warped wood with heavy angle iron, the cell worked well once again. I drilled and tapped six ¼-20 holes for bolts around the edge of the cell so that I could apply pressure at needed places to correct astigmatism when and if the wood warped again. I used this method to advantage to correct slight astigmatism due to some remaining warping in the cell. Do this while looking at slightly out-of-focus star images and adjusting the bolts to apply pressure at the needed places to make the image round. You can check your results immediately by focusing the star.

Performance

My favorite eyepiece is a 2″ diameter 32mm Erfle. This eyepiece in my 2″ eyepiece holder gives 89x with a bit over 0.5° field and a 5.7mm exit pupil. On a dark night, the views of deep sky objects are spectacular, especially after using nothing larger than a 12.5″ for 13 years. Under brighter skies, I occasionally use medium to high magnifications to enhance contrast. Nebular filters also are helpful on large aperture telescopes used near city lights.

The Next Large Thin Mirror Telescope

Roughing the mirror with a sub-diameter tool on a machine works fine, but afterwards a full sized tool preformed with unglazed ceramic tiles epoxied to it would be helpful to keep the curve spherical. The tool backing must be rigid. If the mirror is on the bottom, be sure the base it rests on matches the back surface. The only recommended surface is flat, since the mirror must be rotated often during grinding and polishing. If the mirror is on top, the natural rotation in your hands will average the errors. Be careful not to push or pull the mirror into the lap but rather over the lap when working.

Clearly, much experience on full thickness mirrors is helpful for the amateur doing his first thin mirror. I would recommend using only Pyrex or better material unless you are just experimenting. Hopefully, my success despite the many mistakes I made will encourage you to attempt your first thin mirror. I would enjoy corresponding with anyone attempting this challenge.

Richard J. Wessling
5429 Overlook Drive
Milford, OH 45150

■

◄3Letters

Leaking Dome

Dear Richard / Attached is a copy of a letter I sent to Pastor Richard A. Steeg of Oregon concerning some problems he encountered with construction of his plywood and masonite dome. I hope some of the ideas we tried will aid other amateurs constructing domes using these materials.

Dear Pastor Steeg:

Recently my father and I completed a dome 8′ in diameter of the same materials you used. Spring and summer have been very wet this year, an unusual occurrence for this part of the country, but our building has not leaked since we replaced the original flat rolling roof with the dome; nor have we experienced any problems with condensation.

In your letter to TM you don't say what kind of nails you used, but we used 1½″ resin coated nails and the same glue, Elmer's Professional Carpenter's Wood Glue. The resin nails, which really stick in, make a big difference in holding the masonite gores to the ribs.

Isn't it possible that your glue runs are a combination of water and asphalt caulking compound leaking through the dome seams instead of running glue?

Our dome seams are butt-joints sealed with White Silicone Caulking Compound and covered on the exterior with 2″-wide strips of 8 oz. canvas soaked in Elmer's Professional Carpenter's Wood Glue. It absolutely does not leak.

To eliminate condensation inside, you could install windows. I plan to use small jalousie windows on two sides for cross ventilation, but some kind of ventilator pointing downward such as the thermostatically controlled type reported in TM#9 by Ronald Wisdom of Beebe, Arkansas. With either system, I cannot see that any ventilation in the dome itself would be required.

Flat black paint inside the dome is helpful but would not be necessary under dark country skies if dome leaks and condensation are eliminated.

But by all means, get rid of that DAP asphalt caulking compound and re-seal the seams with Silicone Caulking Compound. This stuff does not harden, draw up, or shrink away from the seams. Cover this with something like our glue-soaked strips on the exterior. I wanted to use fiberglass, but a body-shop friend who knows the material says that fiberglass won't adhere to masonite. Plywood, yes; but not masonite.

I prefer a better paint than latex, but suspect the blistering is due to that asphalt caulk. I used that unsuccessfully on my rolling roof. Though more expensive, oil-base house paint is better. I used Benjamin-Moore, and the finish is almost like plastic.

Without the asphalt caulk, you don't have to go down to bare masonite since the original latex should make a pretty good primer. We used white primer to prepare the masonite surface for good adherence and you might like to do that. Three or four coats of finish paint should be plenty.

I more than agree with Richard Berry that low-cost, light-weight dome technology is something we all have an interest in. After experiencing both a rolling roof and a domed observatory, I have nothing but praise for the domes.

At present, I'm using an 8″ Newtonian visually (have done so for eleven years), but have recently ordered a 17.5″ mirror to replace the 8″. Mine will be mounted equatorially, and I expect the dome will be an excellent housing for the instrument.

I hope the details of materials we used in our dome might be of help in correction of your problems. I think a dome is worth all the little engineering problems we encounter in this fascinating hobby of astronomy.

John H. Gerrald
1703 Lowell St.
Texarkana, AR

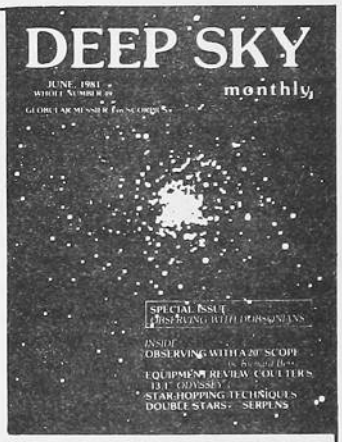
Brazilian Glass Problems

Dear Mr. Berry / Please let me tell you that I finished my first Dobsonian. It is quite puny for a Dob, having only 10″ of primary diameter, but it works like a charm. I am having a tough time taking a look through it beacause my sons, their wives, my granddaughter and other drop-ins are hogging the instrument whenever there is a chance. Now I want to

DEEP SKY monthly, inc.
104 Oakhill Drive, Oxford, Ohio 45056 USA
Telephone (513) 523-5554

DEEP SKY ASTRONOMERS:

Get more out of your observing and photography!



DEEP SKY MONTHLY is the essential magazine for the amateur deep-sky observer and photographer — it's the place you'll find clusters, nebulae, and galaxies reviewed in-depth month after month to improve the quality of your backyard research. *DSM*'s feature articles cover all aspects of deep-sky astronomy — objects, equipment, techniques, and activities. Recent papers include such titles as "*Observing With A 20″ Telescope*" by Richard Berry, "*Gas Hypersensitization Of 35mm Film*" by Dr. Jack B. Marling, and "*Observing Details In Galaxies*" by David J. Eicher. Regular monthly departments cover double stars, variable stars, clusters, nebulae, and galaxies — all matter beyond our solar system! Whatever deep-sky observing interests, you'll be pleased with *DSM*!

DSM is printed on heavy glossy stock, and is produced by a group of amateurs organized as a public, non-profit corporation, with the intention of serving fellow amateurs. Start your subscription today; please allow four to six weeks for delivery of first issue. Best wishes for future observing and photography.

Subscription rates:
$9/yr. in USA ($18/2 yr.)
$12/yr. elsewhere ($24/2 yr.)
Postpaid sample issue: $1
Submit all funds in US currency.

THE ASTROGRAPH

A Bimonthly Magazine Devoted to

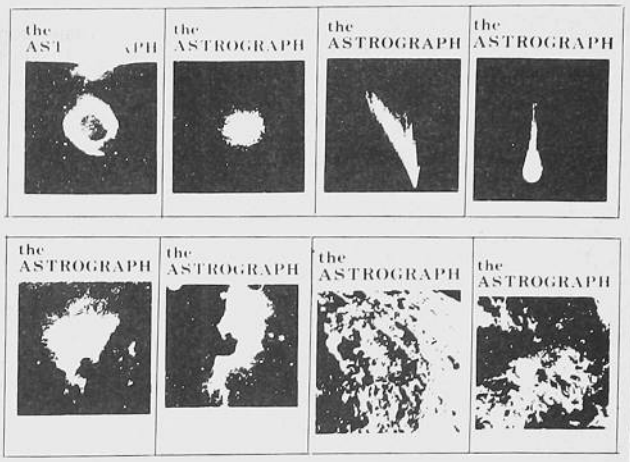
ASTROPHOTOGRAPHY

The **ASTROGRAPH** spans astrophotography from its basic principles to the techniques used by the most advanced amateurs. This publication brings its readers the details, construction, and photographic methods of pictures usually seen in other magazines as illustrations. If you are interested in astrophotography, seek to improve your photographic techniques, or desire to become aware of what others in this branch of astronomy are doing, this magazine is for you. Each year there will be one color issue devoted to color photography.

SUBSCRIPTION RATES

U.S. $6.00 per year • Canada and Foreign $8.00 per year

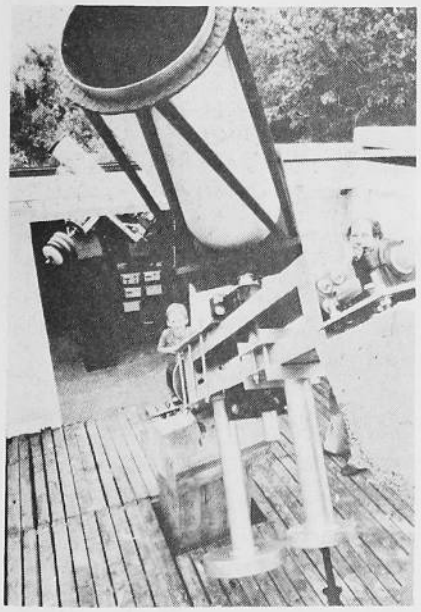
THE ASTROGRAPH • P.O. Box 218 • Dumfries, VA 22026



have a go at a big caliber Dob, but am having trouble about the glass, as it seems that here in Brasil one can't find any glass thicker than ¾". I had written Bob about glued glass, but he advised me against it. Having a blank sent from the States would be prohibitive, first because of transportation expenses and second because something like that blank is considered "superfluous" by our customs authorities and would get a 300% tax on it. Well, let's wait and see how things develop.

Once more, please keep up the wonderful work you are doing with TM. All the best to you.

Werner Scheliga
Rua Manoel F. de Souza Coelho, 46
04922 Sao Paulo SP
Brasil



Photometric Updates

Dear Richard / In thinking about the factors that limit photometry from less than ideal sites, I became interested in two-star dual-channel systems, including two-telescope approaches to this problem. There are a number of problems involved in this. One of the more severe is the data logging and control problem — now in hand with my work on microcomputer control.

Another is getting sufficent field-of-view. Here I'm taking two approaches: a two-telescope approach using a 16" Cass and a piggybacked, offsetable 8" Cass, and working both channels through the 16" Cass. Frank Melsheimer at DFM Engingineering kindly did the optics and baffle design for a 1° FOV.

The biggest unknown is how rapidly the extinction noise decorrelates with increasing angular separation between the comparison and the variable star. The noise must remain correlated for the system to be effective. Don Fernie at DDO did a two-telescope run last summer with 2° separation and got what looked like good results. He and Ed Nather at University of Texas now encourage me to make systematic measurements on this question.

Russell M. Genet
Fairborn Observatory
1247 Folk Road
Fairborn, Ohio 45324

English Amateur

Sir / Having discovered your magazine "Telescope Making" just this week, and having only seen Nos. 1-9, I have no idea whether you are still publishing it. I do not subscribe to Sky and Telescope so I may have missed your demise and probably all other relevant data concerning your publication.

I would be most grateful if you would supply me with the following information so that I may take steps to obtain all back issues available and proceed with future subscriptions.

1) Are you still producing Telescope Making?

2) Does the original price of 9 dollars per year (overseas) still stand?

3) Do you have an agent in my country with whom I should do business?

4) Do back issues cost the same as the present ones?

5) Are back-issues available as far back as No. 1?

As I say, I have only discovered TM this week and feel as if I had missed out on a major part of life, being a keen telescope maker. I agree wholeheartedly with your applied alternative technology articles. The Dobsonian hit me like a bomb. I was completely taken over by its simplicity and cunning. I have been looking for a design that I could complete with a large aperture and moreover with a thin mirror blank. Practically all my telescopes have been made of wood and scrap materials. The last one, a Newtonian with 8.75" f/3.7 mirror I sold privately for 150 pounds to fund my latest instrument, a 5" refractor. I found the fast mirror no trouble at all when I resorted to small laps to deepen the sphere to a parabola. It null tested on a star without any sign of zoning, turned edge or correction faults! Not bad for a first reasonably large mirror.

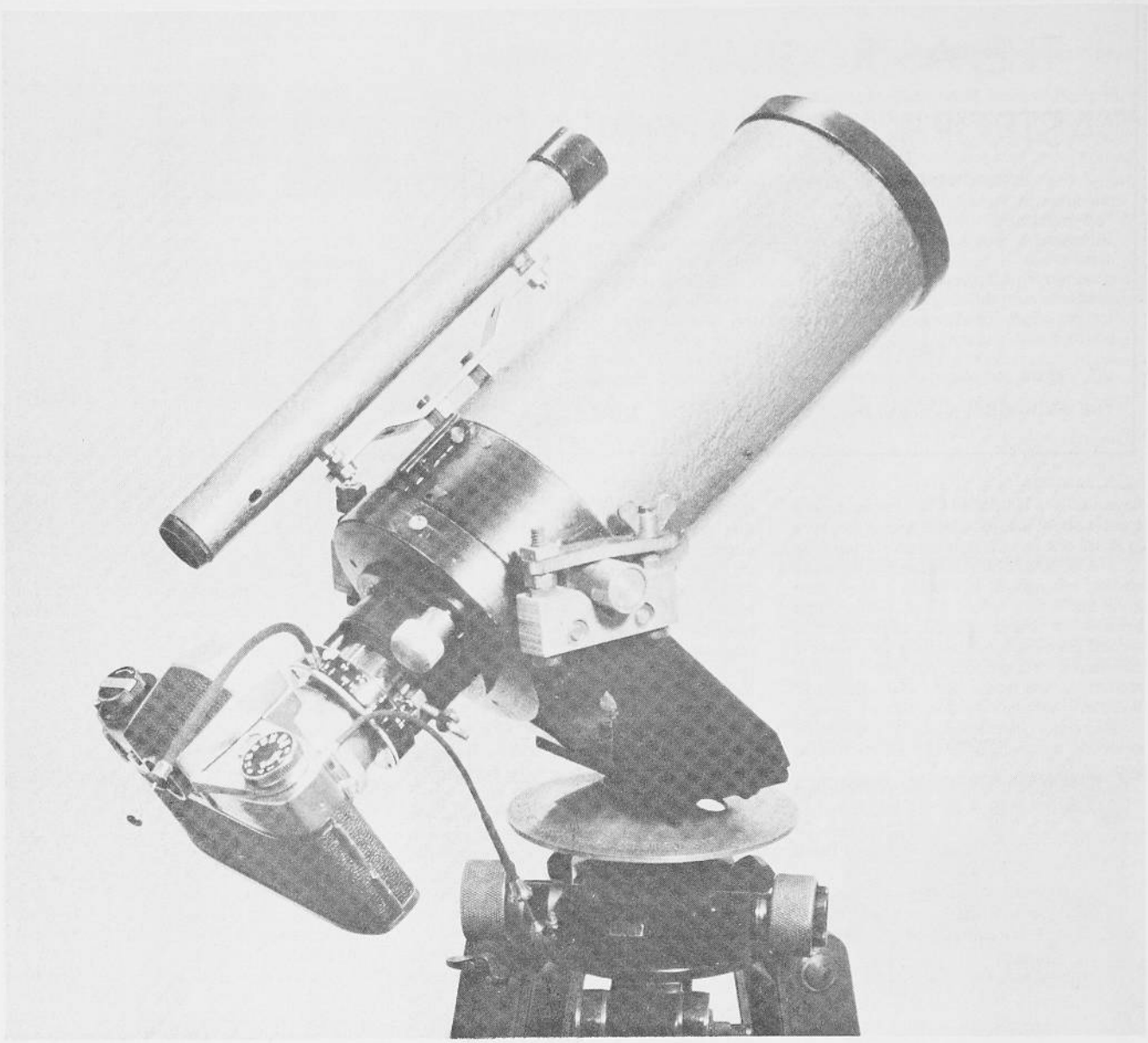
Previous to that I had made the crown blank into a lens for a simple f/20 refractor, and it worked well. The blank was a hard crown of little dispersion. I have also built a number of grinding/polishing machines to work most of my surfaces and the latest has a capacity of about 24", which has a thick cast-iron turntable 24" diameter and a similar stroke. All components are scrap except the small V pulleys and belts. I turned the large V pulleys on a faceplate in a Black and Decker drill. They are simply disks of 13 ply (birch) plywood with a close approximation (turned on the edge) of a V groove, using ¾" chisel. And it works!

I have a strong desire to make a 16" Dobsonian with a thin pyrex blank (1.5") that is available here for about 50 pounds. I shall have to do some saving first though because I would rather not sell my refractor yet. My theory of making a 5" refractor and then selling it to buy 8" blanks for a rather bigger design was dropped when I discovered how difficult it is to mount such a monstrosity and still keep it portable.

As I don't run a car, I had thought to build a trailer to drag a telescope along behind my bicycle, but whether any telescope would cope with our rough roads is questionable. A bicycle powered 16" Dobsonian?

I do hope I am not boring you, but I don't have anyone to talk to much about telescopes. The Society has been taking telescopes to the parks and letting the public

48



Designing Maksutov Telescopes from Scratch

For my three Maksutov projects to date, the carborundum was the most expensive item! I used mangin (back surface) mirrors from old Aldis signalling lamps, bought many years ago for about $1.00 each with R1 already correct (and even bloomed!) for the meniscus lenses of the first two telescopes (of 3.7" aperture). However, the rear (silvered) surfaces of the mirrors had much too large a radius, and had to be reground using the front surface of another identical Aldis mirror as the tool for grinding R2 to the radius required to match the existing value of R1.

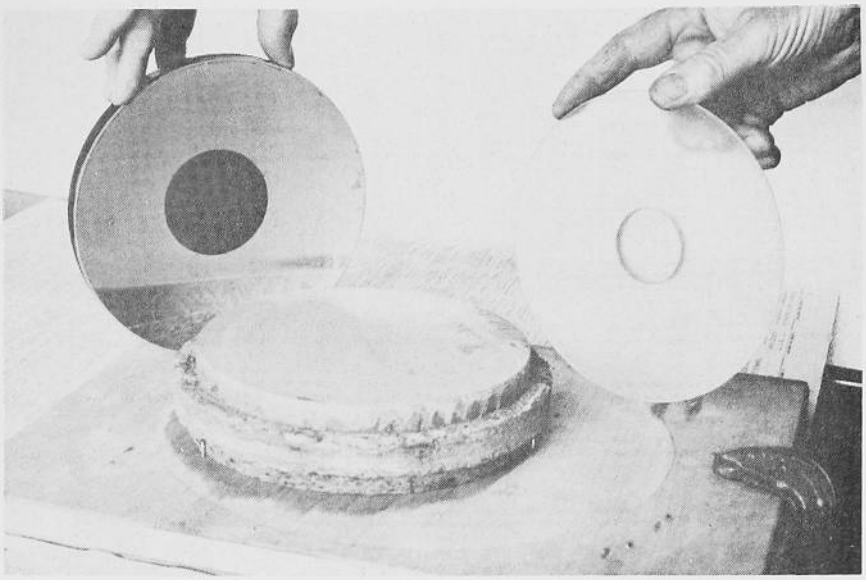
For project No. 3 (of 6" aperture), I used ¼" thick droppings sagged from ordinary green "bottle" glass, bought for about $0.70 each with both curves already fairly close to the required radii and needing only fine grinding to bring them into line. I never did discover what these droppings were actually made for. Star images through the 6" do look a bit odd, but the project gave me a lot of practice and has served for some spectacular bird photography. At present the bottle glass meniscus is being replaced by a proper one made by regrinding the meniscus corrector salvaged (free this time!) from an obsolete Odelca camera made by Oldelft in Holland. These cameras are used for making reduced photographs of X-ray pictures of lungs, and early models are being replaced and can be found throughout the UK in hospital basement stores. Each camera contains a meniscus with the typical specification shown in table 1.

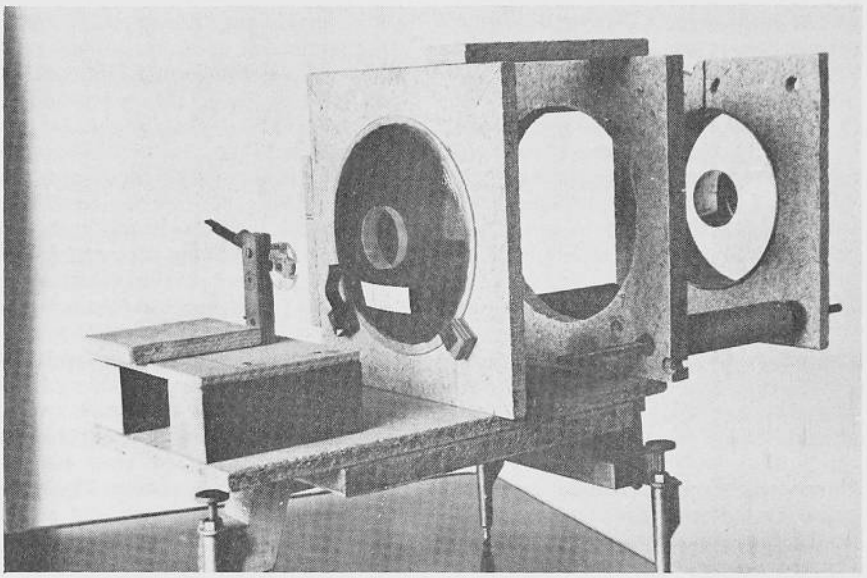
The early TV receivers made by Philips around 1950 used a Schmidt projection system which contained a front-surface mirror 6.7" diameter, made from a ⅝"-thick moulded shell of low expansion glass. This is ideal when reground to a much longer radius (and therefore thin around the edge) and center-mounted Questar style for the primary mirror of a Maksutov. I have used mirrors biscuit cut from these for all my projects, and I still have a small number bought many years ago for about 50 cents each.

However, with such an odd assortment of raw material, it is not practical to rely on scaling existing

Diam.	6·3
R_1	− 4·10
R_2	− 4·83
T_c	0·72
N_D	1·5230
N_C	1·5204
N_F	1·5293

Table 1. *Typical specification of a meniscus corrector from an ODELCA camera. This can be reground to form the meniscus for a Maksutov telescope. The refractive indices are by courtesy of the manufacturer, Oldelft, Holland.*





designs when planning a Maksutov. Up to now, most amateur-built Maks have been based on one of the two designs published by John Gregory in March 1957 *Sky and Telescope*. These were reprinted along with a further collection of Maksutov articles in the form of Bulletin C, and are still available from Sky Publishing Corp. This booklet is essential reading for any amateur who contemplates the construction of a Maksutov telescope.

So, while convalescing from my first attact of "maksutomania," I realized that all other dimensions of an ideal Mak could be uniquely defined as soon as R2 (the convex surface of the corrector) and Tc (the thickness of the corrector) are specified. It followed that there might be many combinations that would perform very well, but for each R2 and Tc there should be only one value for each of the other parameters to give the best possible performance.

It should be, therefore, possible to develop a set of equations which would pull out the other curves and dimensions when fed starting values of R2 and Tc. Other starting factors would also be needed, such as the index of the meniscus, the aperture, and the amount of clearance required between the mirror and the final focus, B, as defined in figure 1.

If such a calculation could also be made to carry straight on with ray-tracing, and be small enough to fit into one of the new breed of programmable pocket calculators, it would form a valuable 'Maksutov package' to free the ATM from the restriction of having to scale from existing designs.

The results have exceeded my expectations, and I now have two versions of such a package or program. The first is adapted for the little Casio FX502P calculator, but could of course

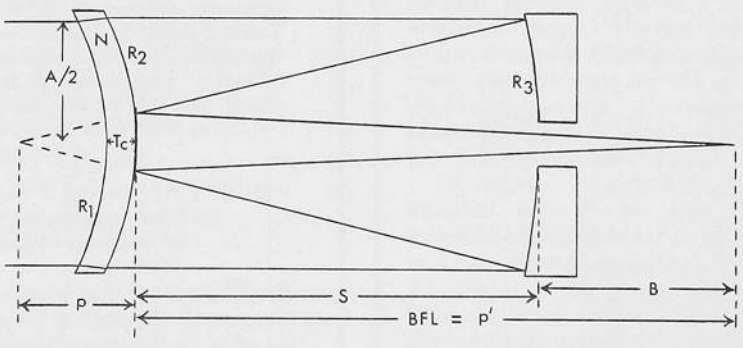
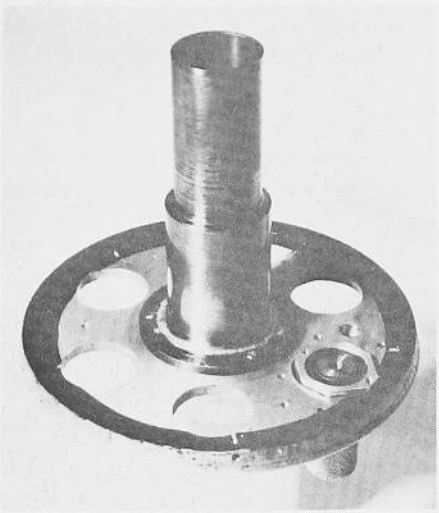
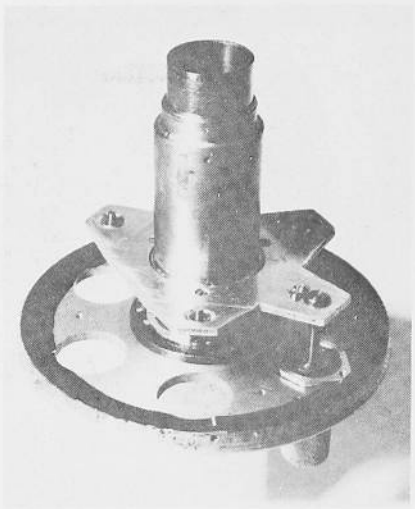


Fig. 1 *Optical layout of a two-element Maksutov to show the meaning of the symbols used in the text.*





be rewritten to suit any other programmable calculator with comparable or greater capacity, or as a program for a computer. When the five items of input data, B, N, Tc, R2 and A/2 (see figure 1) are entered in memories 1 to 5 respectively, the Casio takes about four seconds to design the Mak and display (in succession) the calculated values of R1, R3 and S. A further 22 seconds are needed to raytrace a paraxial and a marginal ray and work out BFL, the back focal length, F, the focal length, LA, the actual Longitudinal Aberration calculated for the marginal zone (usually called spherical aberration), and P-LA, the permissible amount of LA for the design to stay within the Rayleigh limit (based on Conrady). Another three seconds calculates the amount of coma expected from the design, in terms of the OSC, or Offence against the Sine Condition. I take the permissible upper limit of OSC for any telescope used under normal observing conditions as 0.0025, independent of aperture or focal ratio. For more information on OSC see, for example, Wyld's article on page 581 of ATM Vol. 3.

If the radius of, say, the 90% zone is then entered on the keyboard, the program takes about another 10 seconds to raytrace that zone and display the zonal value of LA (by comparison with the already-stored paraxial value) and so on right through the zones to provide the data for plotting a spherical aberration diagram such as shown in figure 2. The zero on the horizontal axis of the diagram represents the point on the telescope axis at which a distant object (a star) is focused by the inner paraxial zone of the optical system. Ideally, all zones of the system, right out to the marginal zone, should focus the star at the same point on the axis; but in practice this is rarely achieved, and the focal points of the various zones are displaced in either direction along the axis, as shown in graphical form by these diagrams.

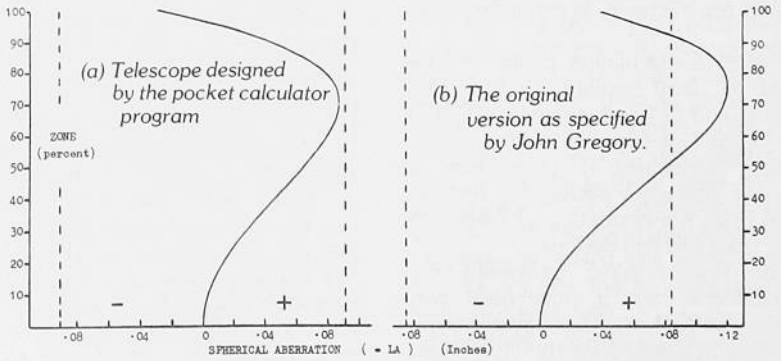
The LA value for any zone is simply the distance that the focus of that zone is displaced from the zero reference point. Simple two-element Maksutov systems of the type considered in this article always produce the kind of curvature seen in figure 2, providing a challenge to the designer to reduce the spherical aberration so that it has negligible effect on the telescope performance. I have not attempted to extend this ray-tracing program to deal with off-axis objects. This would be outside the computing capacity of most pocket calculators, and has been covered already by Roger Sinnott in the programs advertised on page 79 of January 1980 S&T.

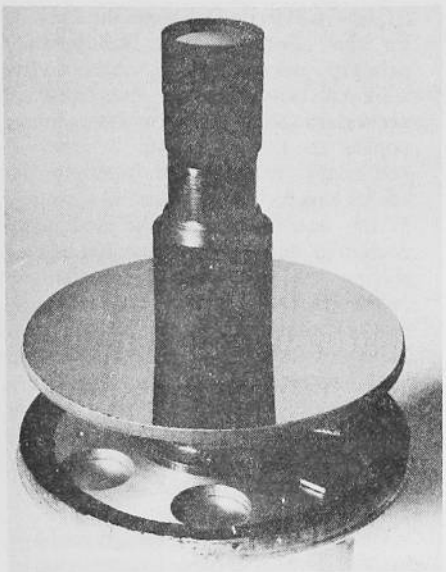
For the example in figure 2a, the Casio was fed with the values of R2, Tc and B (shown in table 2) from the well-known

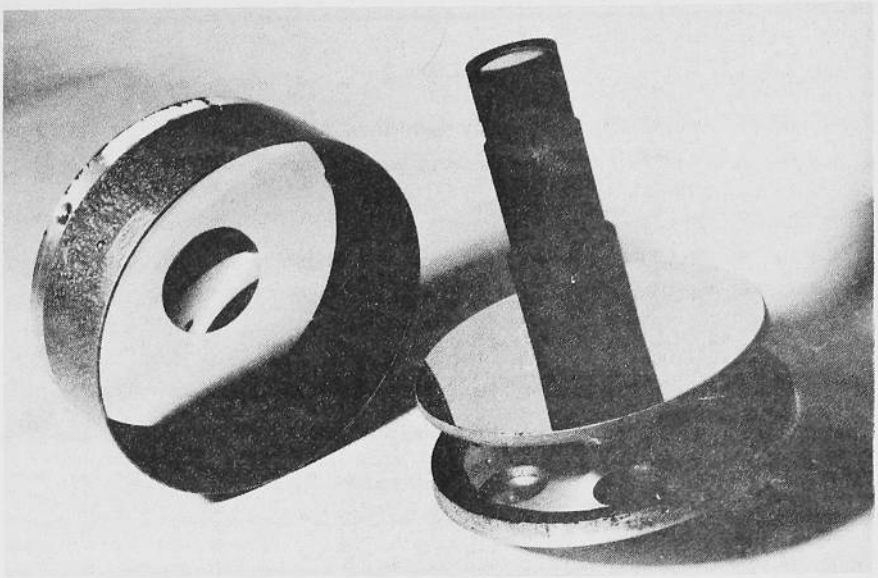
TABLE 2

	(a)	(b)
B	6·590	
N_D	1·517	1·517
T_c	0·520	0·520
R_2	− 6·888	− 6·888
A/2	3	3
R_1	− 6·5866	− 6·583
R_3	− 30·1615	− 29·42
S	12·4824	12·11
BFL	18·8891	18·6904
F	95·5575	92·1092
LA	− 0·0287	0·0392
P-LA	0·0913	0·0848
OSC	0·0017	0·0011

Fig. 2 *Typical graphs of zonal spherical aberration derived from ray-tracing a Maksutov telescope; the permissible limits are indicated by vertical dotted lines.*
Table 2 (left) *(a) The parameters above the dotted line were entered into the Casio FX502P pocket calculator to design a version of the Gregory f/15 Maksutov. Those below the line were calculated and the design was then ray-traced. (b) Using the parameters from the original Gregory specification (above the dotted line) a ray-trace gave the results below the line.*







f/15 Gregory design from pages 7 and 8 of Bulletin C. When designing a Maksutov, the values of R1, R3 and S worked out by the Casio are stored in memories 6, 7 and 8 respectively, and can be recalled for inspection at any time. Any one (or more) of the parameters in the first eight memories (which includes the five starting ones) can be altered, and a straight raytrace done without using the design part of the program. For example, the original values of R1, R3 and S from the Gregory f/15 design (table 2b) were entered in memories 6, 7 and 8 for the raytrace leading to figure 2b. The other starting parameters were already stored in memories 1 to 5 from the calculation leading to figure 2a. The original Gregory version (right) strays outside the permissible aberration limit around the 70% zone, whereas the version designed by the Casio (left) has a slightly longer focal length, but is already just within the limit, at least for D light.

The permissible limit of LA is sometimes increased progressively for inner zones, but I prefer to try to stay within the limit calculated for the full 100% marginal zone, plotted as vertical dotted lines in figure 2 and subsequent figures. The formula used in the program to calculate permissible LA was taken from the booklet *Optical Design and Ray-Tracing by Pocket Calculator* by T.D. Settimi, available from Innovative Optical Material, Box 3648, Riverside, Calif. 92519, USA.

The complete program (including ray-tracing) uses the full 256 program steps in the Casio FX502P. It can be loaded into the Casio without any previous knowledge of calculator programming. All programs and stored data remain in the Casio even when it is switched off; once the program has been loaded, either by hand from a list of the 256 keystrokes, or directly from a pre-recorded cassette tape played in an ordinary recorder via the Casio FA-1 optional adapter, this calculator is ready at all times to design or raytrace Maksutovs at the flick of a switch. It is relatively inexpensive, has a 1300-hour battery life, the ability to act as a music synthesiser, and the intelligence to switch itself off after 14 minutes if its owner forgets to do so.

In the design part of the Maksutov package the following six equations are solved. This can, of course, be done with any small non-programmable calculator equipped with scientific functions — but watch the number of significant figures! Although results are usually quoted only to four decimal places, it is necessary to use a 10-digit calculator to get the right answers. One with only 8 digits will give results which are quite accurate enough for most practical purposes, but are sufficiently different from the ones quoted here to make you think that you have made a mistake somewhere in the calculation.

$$R1 = 1.025\ Tc\ (1\text{-}1/n^2) + R2 \quad (1)$$

$$W = (10.53\ R1^4/Tc)^{1/3} \quad (2)$$

$$BFL = p' = B + 0.433W \quad (3)$$

$$p = R2\ p'/(2p' - R2) \quad (4)$$

$$R3 = -W(1\text{-}4p^2(p/p'+1)^2/WR2)^{1/2} \quad (5)$$

$$S = 1.03(p\text{-}R3/2) \quad (6)$$

Be careful with the signs; all three radii and p are left-going in figure 1 and must therefore have negative values.

Equation 1 appeared in Wright's article in ATM Book 3, page 579, but without the added factor 1.025, and it also appears in Gregory's original article. Settimi added the factor 1.03 (page 25 of his book) in order to minimize chromatic aberration at the 70% zone, but I have found that the slightly smaller 1.025 is better. Settimi's factor pushes the minimum aberration out too far, almost to the marginal zone.

Equation 2 is an approximation (for Nd=1.523) of equation 5 in Wright's article, page 580. It was given to me years ago by Horace Dall, but Dall's version used the factor 10.36. I found by trial and error that 10.53 gave better overall results in my design package under a wide variety of conditions. This equation predicts the correct value of R3 which then has to be modified in equation 5 to allow for the aberration of the secondary.

Equation 3 is entirely empirical, and the factor 0.433 was found by trial and error. As far as I know, the equation has not appeared before. I had to introduce it here because a numerical value of p′ is needed in order to solve for p in the next stage of the design sequence.

Notice that the solution of each equation gives the value of a factor which is needed for solving the following equation so the whole process runs through the calculator as a series of sequential steps. I consider this logical flow in designing a Maksutov one of my main contributions — for example, Settimi's method of designing a Maksutov (pages 25 and 26 of his book) is a most cumbersome affair!

The value of B is chosen to suit the intended use of the telescope, for example, to give room for a star diagonal or a camera coupling system. About 6 or 8 inches is usually enough for B. If you want to move the final focus farther from the mirror, enter a slightly smaller value of S and repeat the raytrace.

Equation 4 is old hat! It is just a re-arrangement of the standard Cassegrainian formula that appears, for example, on page 63 of ATM-Vol.1.

Equation 5 is a slight re-arrangement of the one in S&T, January 1962, page

Table 3

	(a)	(b)	(c)	(d)	(e)	(f)
R_3	- 43·39	- 43·134	- 42·886	- 42·630	- 42·366	- 42·092
S	18·541	18·413	18·289	18·161	18·029	17·892
BFL	23·0441	22·8631	22·6910	22·5167	22·3404	22·1610
F	140·025	138·112	136·292	134·447	132·580	130·678
LA(100%)	- 0·0317	0·0001	0·0300	0·0600	0·0900	0·1202
P - LA	0·1961	0·1907	0·1858	0·1808	0·1758	0·1708
OSC	0·0008	0·0006	0·0004	0·0002	0·0000	- 0·0003

The original Gregory f/23 design (a) was ray-traced to give curve (a) of Fig. 3. The marginal spherical aberration was then made successively more positive by decreasing R3 and S as shown here (the decrease in S is half the decrease in R3). Other parameters, common to all coulmns, were: R1 = -8.040; R2 = -8.293; ND = 1.517; Tc = 0.448; A/2 = 3

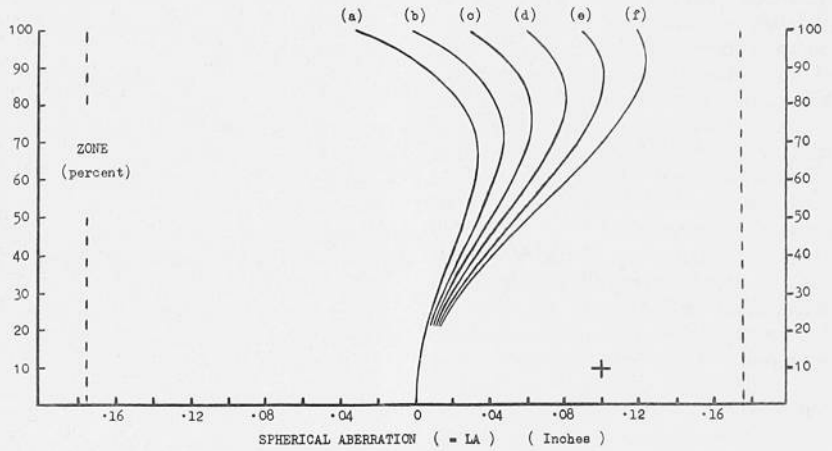


Fig. 3 *Zonal spherical aberration of the original Gregory f/23 Maksutov (a) described by John Gregory in 1957. Curves (b) to (f) show the effects of progressive reductions in R3, with S reduced each time by half as much as R3. the focal length remains relatively unchanged, as shown in Table 3.*

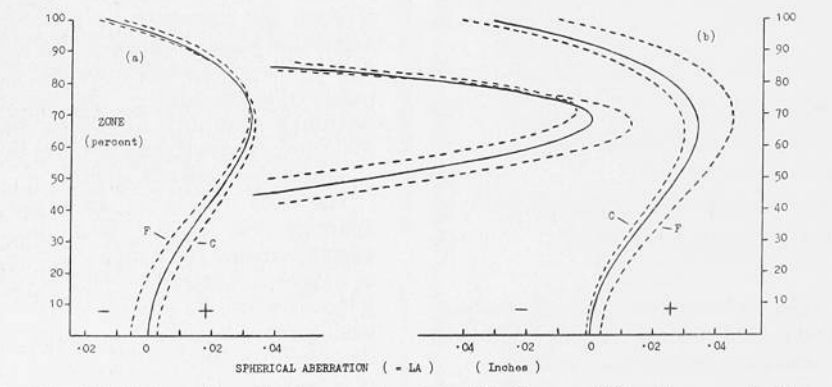


Fig. 4 *(a) The pocket calculator version of the John Gregory f/23, with curves for C and F light added to show that achromatism is best at about the 80 percent zone. (Inset) The crossing points of the three curves in (a) are replotted here with a ten-times expansion of the horizontal scale.*
(b) The original Gregory f/23 was not fully achromatic at any zone, as shon by the absence of crossings in this ray-trace of Gregory's specification.

51, where Horace Dall gives the formula for the ellipticity of a Dall-Kirkham primary necessary to correct the spherical aberration of the spherical secondary. The same formula obviously applies to the Mak with a spherical secondary, and its use converts the earlier intermediate value of R3 (called W in my equations) into the final fully-corrected value of R3. This equation was given to me (along with equation 2) many years ago by Dall when I was pestering him in letters to find out how to design a Maksutov from scratch, without scaling from existing designs.

Although it should be obvious that my equation 6 should indicate S = p-(R3/2), I have found it necessary to add the empirical factor 1.03 to get the right results.

While working up the design package for the TI-59 machine, I experimented with more complicated versions of equations 2 and 5, which are required to make B come out close to the target value under a wide range of conditions. In the end, I returned to these six fairly simple equations when trying to write the program into the Casio. If B does not match the target value at the first attempt, it is easy to ray trace with a slightly different separation to give the required value for B.

My raytracing is based fairly directly on the principles contained in the flow chart on page 14 of Settimi's little booklet, but it now has so many short cuts and loops that its origin wouldn't be recognizable. The only other formulae directly involved are for calculating OSC and spherical aberration tolerance, which were taken from pages 6 and 7 of Settimi's book. I have only recently taken up raytracing and have not yet progressed to anything more complicated than Settimi.

These six equations above will usually produce a Maksutov design which is already within the Rayleigh limit if the initial values entered for R2, Tc and B are sensible. Badly chosen or mutually incompatible values for the starting parameters will naturally produce a nonsense result. If the spherical aberration curve wanders outside the permissible limits, as for example in the original Gregory f/15 in figure 2b, it is easy to tilt the curve in either direction. The trick for pushing the marginal LA towards a more positive value (i.e. to tilt the curve to the right) is to repeat the raytrace with a slightly smaller numerical value for the radius of curvature of the primary mirror and at the same time decrease the separation by half the amount subtracted from R3.

For an example of this trick in operation, the original Gregory f/23 design on page 7 of Bulletin C was raytraced by the Casio and is plotted as

T_c	0.2	0.3	0.4	0.6	0.8	1.0	1.5	2.0
R_2	-4.7000	-5.4000	-6.1000	-7.1000	-8.0000	-8.8000	-10.4000	-11.9000
R_1	-4.5841	-5.2261	-5.8682	-6.7522	-7.5363	-8.2204	-9.5306	-10.7408
R_3	-23.4118	-25.3596	-27.6363	-29.9175	-32.0750	-33.9180	-37.0440	-40.3136
S	9.8125	10.5612	11.4850	12.3205	13.1368	13.8326	14.9560	16.2120
BFL	15.9609	16.8014	17.2297	18.3773	19.1631	19.8039	21.2631	22.1066
B	6.15	6.24	5.74	6.06	6.03	5.97	6.31	5.89
F	90.01	90.02	90.04	90.00	90.01	90.01	90.01	90.00
LA(100%)	-0.0250	-0.0250	-0.0250	-0.0250	-0.0250	-0.0250	-0.0250	-0.0251
P - LA	0.0810	0.0810	0.0811	0.0810	0.0810	0.0810	0.0810	0.0810
OSC	0.0022	0.0021	0.0018	0.0017	0.0016	0.0015	0.0014	0.0013
LA(70%)	0.4324	0.2430	0.1389	0.0738	0.0423	0.0258	0.0088	0.0004

Table 4. *The Casio FX-502P was used to design and ray-trace a family of 6 inch aperture f/15 Maksutovs with identical focal lengths, image positions and marginal spherical aberrations. Notice from Fig. 5 that the zonal spherical aberration improves with increasing menisxus thickness, all the way to an impractical 2 inch thick meniscus.*

figure 3a with a marginal LA, value of -0.0317. The curve was then nudged successively to the right, toward more positive values of marginal LA, by decreasing R3 and S as shown in table 3. If S is decreased each time by half as much as R3, the focal length decreases only slightly, and can be restored exactly to the original value by a very small change in S alone, since the focal length is extremely sensitive to changes in S that are too small to have any other effects.

If you want to hold the focal length more constant during the nudging operation, then decrease the separation by 0.534 times the amount subtracted from R3. Like all telescopes with a large focal ratio, the Gregory f/23 design is very tolerant, and all of the curves in figure 3 are well within the permissible limits for spherical aberration.

When a set of zonal raytraces has been completed for D light, the refractive index value stored in memory 2 can be changed to that for C light (red, 6563 angstroms) and a fresh set of zonal traces completed, followed in turn by a set for F light (blue, 4861 angstroms) to give a complete picture of the color correction achieved by the design. Equation 1 aims for best achromatism at the 70% zone, as shown by the positions of the crossing points of the three curves in figure 4a. For this example, the version of the Gregory f/23 calculated by the 'design' part of the program in the Casio was used. Traces in F and C light were added, assuming values of 1.523 and 1.514 for Nf and Nc. The details in the region of the crossing points in figure 4a were replotted on a ten-times expanded horizontal scale in the inset to show that the best achromatism is achieved in this example at about the 80% zone. Figure 4b shows the result of raytracing the original Gregory f/23 in F and C light. The slightly larger radius specified by John Gregory for R1 did not produce full achromatism at any zone, as shown by the complete absence of crossing between any pair of the three curves. It would be interesting to hear from readers who built this telescope to the Gregory specification, whether the lack of full color correction was in any way visible under actual observing conditions.

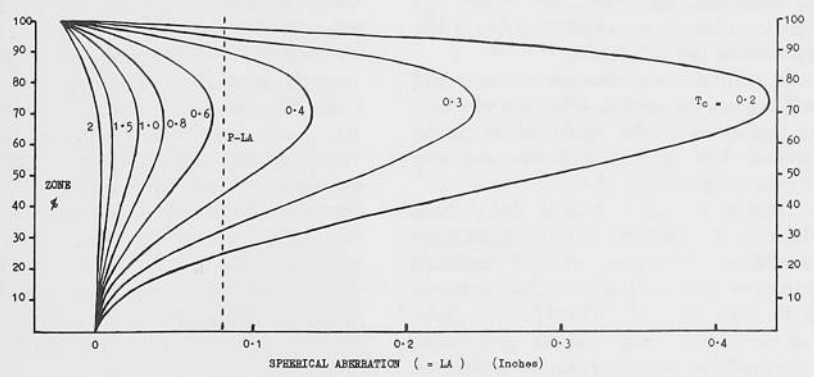
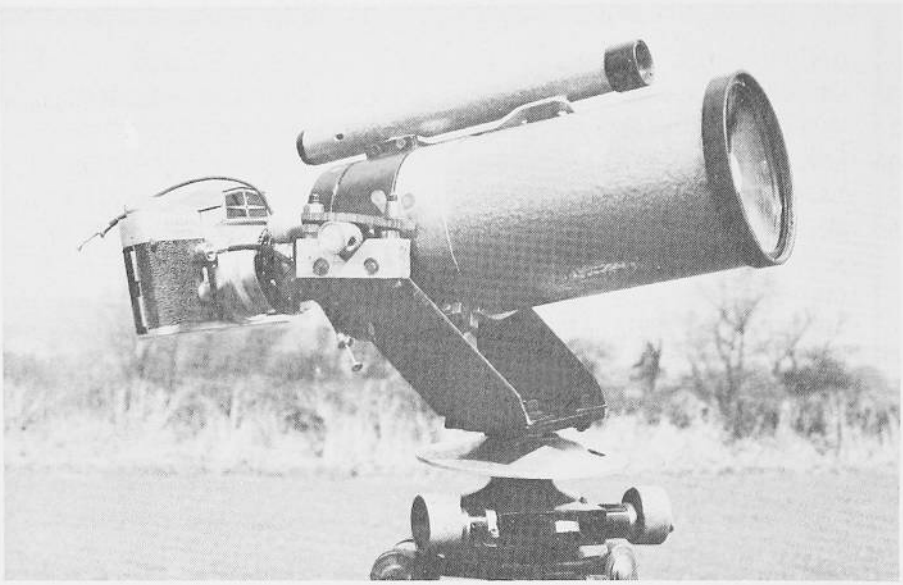


Fig. 5 *Zonal spherical aberration of a 6 inch f/15 two-element maksutov for different meniscus thickness (Tc) when the overall focal length and the image position are kept constant.*

So far, all my examples have been based on the Maksutov designs published by John Gregory because they are already familiar to anyone sufficiently interested to read this article. The real value of my 'Maksutov package' lies in its ability to break new ground by designing fresh families of Maks. For my last example, we will use the little Casio to design and check a new family of 6" f/15 telescopes with meniscus thickness ranging all the way from 0.2 to 2.0 inches, in order to see if the performance really is best when the thickness is about one tenth of the aperture, as originally specified by D.D. Maksutov (see page 273 of Bulletin C) and subsequently followed by all designers of Mak systems. To make sure that the effect of meniscus thickness is not confused with effects caused by changes in the other telescope parameters, we will insist that all the members of the family must have exactly the same values for overall focal length (90 inches) and marginal spherical aberration (-0.0250), and also that the distance of the image behind the mirror will stay within the limits 6" plus or minus 0.5".

For each selected value of Tc, guess a likely value for R2 and allow the Casio to design and raytrace the system. Unless you are very lucky, F and LA will be a long way from the required values. It will need many trial-and-error attempts to nudge them to the right values, using the trick already described in connection



with figure 3 and table 3 to drive LA to the target value of -0.0250 inches, while adjusting the separation to drive F to the target value of 90 inches, remembering that the two adjustments are interdependent.

When these goals have been achieved to a high degree of accuracy, you will probably find that B has ended up too far from its target value of 6 inches. If B is too small, start again with a smaller value for R2 and repeat the sequence until you eventually score a bullseye on all three targets simultaneously, or alternatively until either you or the Casio has a mental breakdown. My table 4 makes it look easy by listing only the final successful line of the sequence for each selected thickness of meniscus. A set of zonal raytraces is then done for each design, but to save space only the value for the 70% zone is tabulated in table 4. The full zonal results are plotted as figure 5.

The result was entirely unexpected, and contradicts the generally held belief that a Mak meniscus works best when its thickness is about one tenth of the aperture. This was even 'proved' on pages 26-27 of *Optical Design and Ray-Tracing by Pocket Calculator*, where author Settimi makes the mistake of leaving R3 fixed for all three designs used in his example, and changes only the separation to accommodate the different thicknesses chosen for the meniscus. It is essential to adjust both separation and mirror radius for each meniscus thickness, using the methods described here, otherwise each design gives a quite different telescope and therefore a comparison of aberrations is not meaningful.

The radii of the corrector surfaces in this exercise varied from an approximate 4.5″ for the 0.2″ thickness to an 11″ radius on the 2″ thickness. The primary mirror likewise became longer in radius — from about 23.5 to 40.25 inches. The longer radii do have an advantage of easier fabrication and testing, but the added weight of the thick meniscus is a very serious factor. Note that the separation of the corrector and primary mirror changes from 9.8″ to 16.2″, making the tube both longer and more awkward to handle.

By also nudging each design to exactly the same value of marginal LA, the zonal spread of LA can be compared directly by plotting the aberration curves as a family starting and ending at the same values, figure 5, where it is immediately obvious that spherical aberration decreases steadily as Tc is increased, all the way to a quite impractical 2 inches. However, the system comes within tolerance only when the meniscus thickness exceeds the magic one tenth aperture value which is probably the origin of the misconception that there is an optimum thickness for a Mak meniscus. Perhaps the optimum is based only on economics of cost and weight of the meniscus, and reflects the fact that a professional designer will never go further than is necessary to bring the system within tolerance.

In contrast, a dedicated amateur TM will pursue the elusive goal of perfection to the ends of the earth, although he knows that his eye will not see any improvement beyond about ⅛-wave.

Notice in table 4 that OSC also decreases steadily with increasing meniscus thickness, unlike Settimi's example (page 27) where OSC appears to increase along with Tc. My example in figure 5 also brings out the point that marginal LA alone cannot be used as a criterion to judge a telescope performance, since it is clearly quite easy to nudge any Mak to any selected value of marginal LA (including zero), regardless of the fact that the zonal LA may then wander a mile outside the acceptable limit, as in the case of the 0.2 inch meniscus in figure 5.

A second version of the package is available from the author (on magnetic strip, if required) for the popular Texas Instruments TI-159 calculator used along with the PC100C printer. Fed with the same five starting parameters, this produces a full printout of the telescope design and raytrace, and then, if required, runs automatically through the zonal raytraces at all three colors. Finally, a modified version of the TI-59 program is available for use when the PC100C printer is not attached.

I am afraid there is no spare memory left in the Casio or the TI-59 to help you with the grinding and polishing! — that little job you must do yourself.

Bill Sutherland
13 St. John's Crescent
Whithurch,
CARDIFF, CF4 7AF
Wales, UK

Ed Note: Amateur astronomers and telescope makers never cease to amaze me with their interesting and unusual ideas and instruments. Now, from the field of pocket programmable calculators comes an article that shows extreme ingenuity and clever application of known standards of lens design to an instrument long popular with the amateur, the Maksutov.

The field of optical design and ray tracing is a complicated one, as discussed in TM#10, so after receiving Mr. Sutherland's article, I sent the material to the original designer of the most popular Maksutov telescope, John F. Gregory. His comments on the results of this English physicist follow. The material was also sent to lens designer David E. Stoltzmann (see his article on the aberrations of a Newtonian in TM#12) and his comments on the work of Mr. Sutherland also follow. These comments speak for themselves of the value of the article for the amateur interested in such work.

One of the standards in lens design over the years has been the work of A.E. Conrady, but his formulae are arranged for hand calculators with a set of trigonometric tables. As Mr. Conrady's son-in-law points out in *Lens Design Fundamentals*, for modern electronic machines, these equations are not suitable. This is most interesting, since Mr. Sutherland used the old basic Conrady formula in his raytracing, and as one can readily see, obtained fine results.

However, as Gregory mentions in his analysis of Sutherland's results, more modern methods of analysis show the apparent discrepancy in the 1957 f/15 Gregory design is not real — and the

original design is still somewhat better, even if only a little. The analysis of the design using the intersection point in the focal plane measured along the axis, BFL or L′ in the programs, has been superseded by the method of plotting, in the focal plane, the location of a ray determined by the situation of the distance from the true location divided by the tangent of the ray as it crosses the optical axis. Information on how to apply this method can be found in Warren Smith's *Modern Optical Engineering*, pages 68 through 71.

The actual program for Mr. Sutherland's calculations is not presented, and we do not advise that you fabricate a telescope from these figures. However, in the interest of clarity, we could not omit the optical specifications. We therefore want to warn you that we don't recommend using these specifications to fabricate a set of optics.

The telescopes made to this time by Mr. Sutherland involved adapting surplus optical equipment to designs in which the focus from the secondary spot lies between the mirrors and is relayed out to a camera by a series of lenses. The actual Gregory design has not been used except as an example in his calculations.

Copies of the programs of Mr. Sutherland for the TI-59 and Casio calculators can be obtained from Bob Cox, 205 E. Elm St., O'Fallon, MO 63366 or by writing directly to Mr. Sutherland for further technical information.

For a copy of the program steps and operating instructions for the Casio FX502P (which also will operate in the newer Casio FX602P), send a long SASE with two stamps to the O'Fallon address. Those with a TI59 machine, please send the same long two-stamp SASE envelope. If two magnetic cards are sent with the TI-59 request, they will be returned with the program. However, due to some differences in the TI machines, cards made on one machine do not always run on another, so there is no guarantee that the returned cards will work. TM cannot assume any responsibility for failure of cards to run on other machines.

R.E. Cox

Many thanks for the prepub look at Sutherland's paper. He's done a lot of work and has some valuable curves, particularly the family showing the dependence of zonal residual upon corrector thickness. From these curves, one would choose a very thick corrector and benefit from small zonal residual. And Table 4 shows you would benefit from flatter radii and smaller OSC too. But the price to be paid for these benefits is high, as you go from 0.4″ to 2″ thick. Glass cost more than doubles, tube weight and CG position worsen, and the obscuration from the secondary grows 19% to 25% (and that's without baffles). If we could roll back the calendar 25 years to when my first Mak was built, I think a t/D ratio of 1/9, or even 1/8, would have been a better choice for the TNs.

Relative to Bill's comments and conclusions about the old f/23 and f/15 Greg Maks, I would say that Figure 3 shows the negligible zonal residuals as a small fraction of the permissable LA ± 0.17″. Even when the C and F curves (from Figure 4b) are put on Figure 3, the total errors are disappearingly small, as borne out by many fabrications of the design over the years.

The f/15 original was designed using h/tan U′ curves, as this gives height in the focal plane vs. tan of the angle the ray makes with the optical axis. Most optical designers use this rather than the H/LA curves, since a focal shift may be affected by a simple rotation of the reference lines. By redrawing Figure 2 as h/tan U′ curves, the advantage of design b will be more obvious. In either case, zonal aspherization is recommended, which should be easier with b than a.

John Gregory

The systems produced by Mr. Sutherland's program are very well corrected. (I checked the Tc = 0.6 and Tc = 2.0 systems in Table 4, and the numbers I obtained agree well with his.) I agree completely with his idea of giving the ATMs a chance to reconfigure the basic Gregory design, and as long as they monitor the OSC and raytrace the systems in three colors, there should be no problems with the "on-axis" raytrace program.

Generally, the lateral color over the small field-of-view of the Maksutov is of no concern. I would caution anyone attempting to substantially change the designs, except for scaling up or down, to beware of degradation in the off-axis performance. I am referring to someone trying to design an f/5.6 system, for example, such as those given by Simmons in S&T.

In the literature, I have not seen it mentioned that the "optimum" corrector thickness is 1/10 the aperture, at least from an optical correction standpoint. I suspect, rather, that this value has been adopted primarily for fabrication and mechanical reasons. Mechanically, the shell is quite stable and rigid at a thickness 1/10 its aperture due to its steep curves. A thinner corrector would be difficult to fabricate accurately without springing, while a thicker corrector will add expense, substantial weight, and a longer tube assembly (5″ in the case of the 2″ corrector example).

When I read Maksutov's original article, it did not imply to me that the "optimum" corrector thickness is 1/10 the aperture, but rather is simply one of the initial constraints he imposed on the design. As another example, the glass choice is certainly not an "optimum" optically either, but represents an acceptable trade-off for many other reasons. Once these assumptions have been made, one can go about optimizing the design as best one can.

Regarding the issue of the meridional raytrace, I agree that it will be sufficient to perform the design work for this type of system. A meridional ray fan will tell the whole story on-axis, and if one monitors the OSC calculation during the course of the design, good field performance will be obtained as well. The meridional trace will also indicate how much aspheric correction needs to be applied to eliminate SA completely, if this is desired. Then in autocollimation, the on-axis performance can be tweaked to perfection by local figuring.

If the correction is applied to the meniscus, then the off-axis performance is relatively unaffected, since the corrector is the aperture stop, and the aspheric contribution depends on the height of the chief ray — which is zero for the aperture stop. Because of the steep curvatures of the corrector surfaces, I would not suggest putting the correction there.

It is well known that a thicker meniscus will improve performance in a Maksutov system, as cited by Smith, for example, in the second to last paragraph on page 396. Smith is discussing a concentric system here, but one would expect the same general characteristics to be true of the Maksutov. What did somewhat surprise me was that the axial color of the thicker correctors in Sutherland's designs is improved. The reason it does not get worse (it would get worse if the system were concentric and the corrector made thicker), is that his systems have four design variables other than the thickness of the corrector. The reason Settimi's example does not get better with a thicker corrector is that he only uses two design variables other than the thickness of the corrector. Settimi is not "in error" as suggested by Mr. Sutherland, but simply illustrating a raytrace using fewer variables. I do not think Settimi meant to be exhaustive in his examples and claim them to be "optimum" designs; illustrative — yes, exhaustive — no.

All in all, it is an interesting article and should benefit many ATMs. Regarding the corrector thickness: it does not shatter any long-standing optical myths that I know of. It does represent a perturbation to a mechanical and financial criterion long since adopted by ATMs building the "recipe" designs given to them.

David Stoltzmann

Blue Pages

Classified Product Directory

BOOKS/INFORMATION

Celestron International ..... 2835 Columbia St., Torrance, CA 90503 (213) 328-9660
Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007
OPTICA b/c ..... 4100 MacArthur Blvd., Oakland, CA 94619 (415) 530-1234
Orion Telescope Center ..... P.O. Box 1158-T, Santa Cruz, CA 95061 (408) 476-8715

DRIVE ELECTRONICS

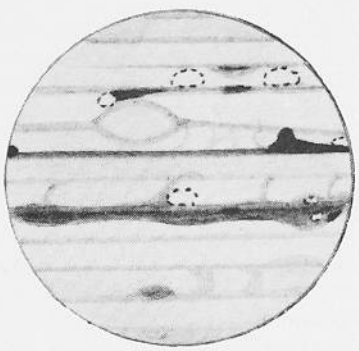
Abraxas Electronics ..... P.O. Box 1093, Littleton, CO 80160 (303) 979-6102
Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007
Orion Telescope Center ..... P.O. Box 1158-T, Santa Cruz, CA 95061 (408) 476-8715

DRIVE MOTORS

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

EYEPIECES

Celestron International ..... 2835 Columbia St., Torrance, CA 90503 (213) 328-9560
Coulter Optical Co. ..... 54121 Pinecrest Rd., Idyllwild, CA 92349 (714) 659-2991
Dodd Co. ..... 7795 W. Ridgewood Dr., Parma, OH 44129 (216) 886-2828
Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007
Manitoba Museum Shop ..... 190 Rupert Ave., Winnipeg, Manitoba, R3B 0N2, CANADA (204) 956-2830
Meade Instruments Corporation ..... 1675 Toronto Way, Costa Mesa, CA 92626 (714) 556-2291



Custom Made Mirrors

We offer custom made classical Newtonian & Cassegrain mirrors. We have fine references. Write for details.

ALCYONE OPTICS, INC.

Department C, 6259 W. Touhy Ave.
Chicago, Illinois 60648 **312-775-3735**

CLOSED THURS.

The above artwork is a small sampling from the deft hand of prolific observer Dan Troiani, who has earned for himself an invitation to Lowell Observatory, Flagstaff, to do drawings of Mars at the eyepiece of the 24″ Clark refractor stationed there! Dan's 10″ Newtonian mirror, fabricated by our resident optician, Daniel P. Joyce (and this was the 240th set of optics he had been responsible for), has been the workhorse of his observing program that has lofted him to pre-eminence not only in planetary artwork, but in other fields as well. He has been among the top ten contributors to the AAVSO in the past three years (and recently reached magnitude 15.5 with his 10″ in northwest Illinois), and he once tracked down 144 galaxies in a single night. A feat in itself, it was compounded by his locating twenty-two clusters and nebulae, the planet Pluto, the quasar 3C-273, eight variable star estimations, drawings of Jupiter and Mars, and observations of Saturn and Venus, bringing the total of significant observations he did for one night to a staggering 180! Telescopes which can do both serious and aesthetically pleasing visual tasks are the ultimate astronomical instruments; but for us at Alcyone, we have been accustomed to it. We actually conduct ATM classes at our well-endowed facilities and have many years experience providing this type of service (even guiding students through the rigors of Cassegrain optics up to 16″ diameter). We understand that telescope performance is determined by careful design features and optical precision, *not* fancy ads or claims.

When you build your own scope, you want to use the best materials available.

UNITRON offers the ATM the finest quality components and accessories for refractors, reflectors and catadioptric instruments. Choose from a wide selection of:

A EYEPIECE HOLDERS

For 24.5mm

Star Diagonal	$15.00
2X Barlow	8.00
Erecting Diagonal	36.00
Erecting Prism	30.00

For 1¼"

Star Diagonal	23.00
2X Barlow	23.25
Erecting Diagonal	40.00
Erecting Prism	27.00

B VIEWFINDER MOUNTING BRACKETS

For 23.5mm finder, pair	$ 8.00
For 30mm finder, pair	10.00
For 40mm finder, pair	13.00
For 60mm finder, pair	20.00
For 100mm guide scope, pair	45.00

C EYEPIECES

1¼" O.D.

40mm Mono	$25.00
20mm Erfle	40.00
25mm Ortho	31.00
18mm Ortho	29.00
12.5mm Ortho	27.00
9mm Ortho	28.00
6mm Ortho	29.00
4mm Ortho	32.00

24.5mm O.D.

25mm Ramsden	$16.00
18mm Kellner	16.00
12.5mm Kellner	16.00
9mm Kellner	12.00
9mm Symm	19.00
7mm Symm	19.00
6mm Ortho	24.00
5mm Ortho	24.00
4mm Ortho	27.00

D CAMERA ADAPTERS

Standard Adapter	$18.00
Deluxe Adapter	35.00

E T-MOUNTS

Pentax-K (Bayonet)	$ 6.00
Pentax (Thread)	7.00
Petri	13.00
Mamiya	8.00
Nikon	13.00
Exacta/Topcon	13.00
Konica	13.00
Canon	13.00
Minolta	13.00
Olympus	16.00

F VIEWFINDERS

Complete with mounting brackets

6X-23.5mm	$ 35.00
8X-30mm	45.00
10X-40mm	60.00
12.5X-60mm	148.00
8X-30mm w/diagonal	63.00
10X-40mm w/diagonal	75.00

G MULTIPLE EYEPIECE HOLDERS

For 24.5mm

Unihex rotary eyepiece holder	$56.00
Deutron double eyepiece holder	49.00

For 1¼"

Unihex rotary eyepiece holder	$56.00
Deutron double eyepiece holder	83.00

H MOUNTED OBJECTIVE

60mm f/8.3	$ 61.00
60mm, f/11.7	61.00
60mm, f/15	61.00
75mm, f/16	124.00
100mm, f/15	235.00

I OBJECTIVE OUTER CELL WITH DEWCAP

For 60mm Objective	$16.00
For 75mm Objective	24.00
For 100mm Objective	45.00

J PHOTOGRAPHIC GUIDE SCOPES

Complete with mounting brackets.

60mm, f/11.7	$152.00
75mm, f/15	285.00
100mm, f/15	548.00

K ASTRO CAMERAS

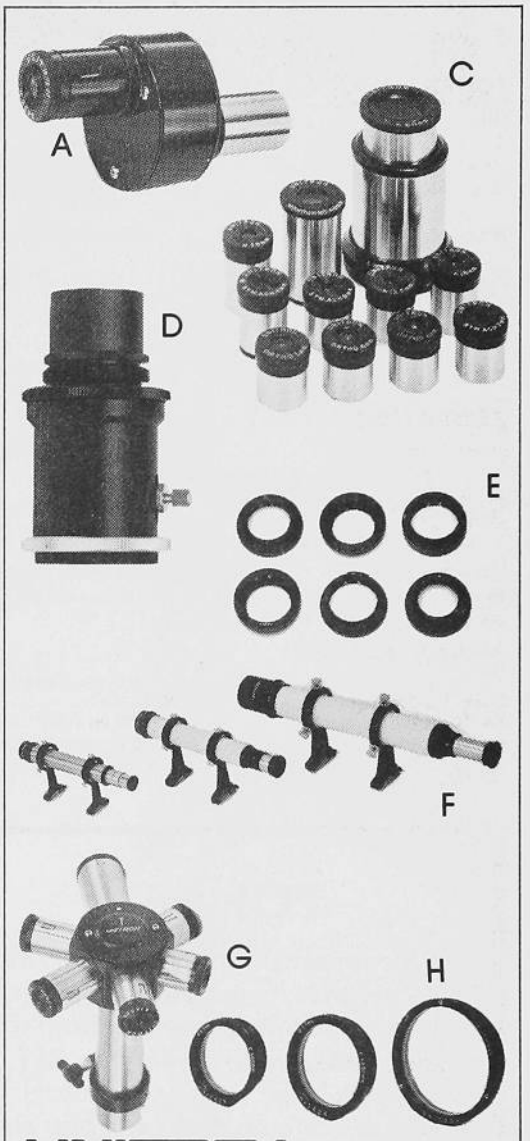
Model 220A, for Unitrons	$305.00
Model 220B, for 1¼" holders	305.00
80mm, f/5 Astrograph	715.00

L RACK & PINION FOCUSING MECHANISMS

Can be adapted to suit individual requirements.

Standard Model for 2.4" Refractors	$ 38.00
Standard Model for 3" Refractors	38.00
Deluxe Model	48.00
Super Model	100.00
Super Model with Focusing Scale	100.00
Coupling Collar for Deluxe Model, to fit 3 1/16" i.d. tubing	11.00
Coupling Collar for Super Model, to fit 4⅜" o.d. tubing	19.00

Prices, F.O.B. destination Continental U.S.A., subject to change without prior notice.



UNITRON

EXCELLENCE BY DESIGN

Send me more information about:

☐ _____

☐ Accessories catalog

UNITRON INSTRUMENTS, INC.
175 Express Street, Plainview, NY 11803, U.S.A.

TM

master charge

VISA

Name _____

Address _____

City _____

State _____ Zip _____

OPTICA b/c ..... 4100 MacArthur Blvd., Oakland, CA 94619 (415) 530-1234

Orion Telescope Center ..... P.O. Box 1158-T, Santa Cruz, CA 95061 (408) 476-8715

Unitron Instruments Inc. ..... 175 Express St., Plainview, NY 11803 (516) 822-4601

W.R. Parks ..... P.O. Box 6683, Torrance, CA 90504 (213) 532-6066

FILTERS

Celestron International ..... 2835 Columbia St., Torrance, CA 90503 (213) 328-9560

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

Meade Instruments Corporation ..... 1675 Toronto Way, Costa Mesa, CA 92626 (714) 556-2291

OPTICA b/c ..... 4100 MacArthur Blvd., Oakland, CA 94619 (415) 530-1234

W.R. Parks ..... P.O. Box 6683, Torrance, CA 90504 (213) 532-6066

LENS KITS

N. Remer Optics ..... Box 306T, Southampton, PA 18966 (216) 355-3086

LENS BLANKS

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

LENSES — CUSTOM MADE

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

LENSES — OFF-THE-SHELF

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

OPTICA b/c ..... 4100 MacArthur Blvd., Oakland, CA 94619 (415) 530-1234

MIRROR BLANKS

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

MIRROR KITS

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

OPTICA b/c ..... 4100 MacArthur Blvd., Oakland, CA 94619 (415) 530-1234

MIRRORS — CUSTOM MADE

Coulter Optical Co. ..... 54121 Pinecrest Rd., Idyllwild, CA 92349 (714) 659-2991

Enterprise Optics ..... P.O. Box 413, Placentia, CA 92670 (714) 524-7520

Jeff Grant ..... 726 Golfview Dr., Charleston, SC 29412

MIRRORS — FLATS

Coulter Optical Co. ..... 54121 Pinecrest Rd., Idyllwild, CA 92349 (714) 659-2991

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

MIRRORS — DIAGONALS

Coulter Optical Co. ..... 54121 Pinecrest Rd., Idyllwild, CA 92349 (714) 659-2991

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

Meade Instruments Corporation ..... 1675 Toronto Way, Costa Mesa, CA 92626 (714) 556-2291

OPTICA b/c ..... 4100 MacArthur Blvd., Oakland, CA 94619 (415) 530-1234

W.R. Parks ..... P.O. Box 6683, Torrance, CA 90504 (213) 532-6066

MIRRORS — OFF-THE-SHELF

Coulter Optical Co. ..... 54121 Pinecrest Rd., Idyllwild, CA 92349 (714) 659-2991

Enterprise Optics ..... P.O. Box 413, Placentia, CA 92670 (714) 524-7520

Meade Instruments Corporation ..... 1675 Toronto Way, Costa Mesa, CA 92626 (714) 556-2291

W.R. Parks ..... P.O. Box 6683, Torrance, CA 90504 (213) 532-6066

MOUNTINGS — COMPLETE

Celestron International ..... 2835 Columbia St., Torrance, CA 90503 (213) 328-9560

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

Meade Instruments Corporation ..... 1675 Toronto Way, Costa Mesa, CA 92626 (714) 556-2291

Unitron Instruments Inc. ..... 175 Express St., Plainview, NY 11803 (516) 822-4601

FOR SALE

Surplus aerial camera lenses, 36" F/8 and 24" F/6, various manufacturers. Each has working iris diaphragm and shutter that may or may not work. Great for RFT; need minus'blue filter for astrophotography (I don't have filters). **$50 each plus shipping costs.** Limited quantities. Glass o.k.

Oculars, Kellner, approximately 28 mm. f.l., in 1¼" barrels. made from surplus 7x50 binocular eyepieces of American origin. Coated. Perhaps not the most gorgeous in appearance, but fine in performance. Give richest field power (7mm. exit pupil) with any F/4 primary. **$9.00 each** postpaid in the lower 48. Limited quantities. Money back if not satisfied.

ALL ITEMS IN STOCK!

Dick Nelson, 3470 Travis Ave., Simi Valley, CA 93063

Free!
SURPLUS
CATALOG

We have gadgets galore . . . industrial and military surplus items that all you telescope makers, gadgeteers, and do-it-yourselfers just can't afford to overlook. If you have the knack for turning a thing-a-ma-jig into a golden opportunity, then our gadget gazette is just what you're looking for. Have an idea that needs some unusual lenses, eyepieces, timers, motors or perhaps gears? How about mirrors, finderscopes, tubing, glass filters or some other such thing? We have the gadget you're looking for. Just send for our latest FREE catalog.

JERRYCO

Write To :

JERRYCO
5700 Northwest Highway
Chicago, Illinois 60646

W.R. Parks ..... P.O. Box 6683, Torrance, CA 90504 (213) 532-6066

MOUNTINGS — PARTS

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

OPTICAL ABRASIVES — BULK

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

OPTICA b/c ..... 4100 MacArthur Blvd., Oakland, CA 94619 (415) 530-1234

OPTICAL TEST EQUIPMENT

Coulter Optical Co. ..... 54121 Pinecrest Rd., Idyllwild, CA 92349 (714) 659-2991

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

PREFORMED TOOLS, LAPS

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

SETTING CIRCLES

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

W.R. Parks ..... P.O. Box 6683, Torrance, CA 90504 (213) 532-6066

TELESCOPE ACCESSORIES

American Science Center ..... 5700 Northwest Highway, Chicago, IL 60646 (312) 763-0313

Celestron International ..... 2835 Columbia St., Torrance, CA 90503 (213) 328-9560

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

Manitoba Museum Shop ..... 190 Rupert Ave., Winnipeg, Manitoba, R3B ON2, CANADA (204) 956-2830

Meade Instruments Corporation ..... 1675 Toronto Way, Costa Mesa, CA 92626 (714) 556-2291

Orion Telescope Center ..... P.O. Box 1158-T, Santa Cruz, CA 95061 (408) 476-8715

Unitron Instruments Inc. ..... 175 Express St., Plainview, NY 11803 (516) 822-4601

TELESCOPE PARTS

Dodd Co. ..... 7795 W. Ridgewood Dr., Parma, OH 44129 (216) 886-2828

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

Enterprise Optics ..... P.O. Box 413, Placentia, CA 92670 (714) 524-7520

Meade Instruments Corporation ..... 1675 Toronto Way, Costa Mesa, CA 92626 (714) 556-2291

OPTICA b/c ..... 4100 MacArthur Blvd., Oakland, CA 94619 (415) 530-1234

W.R. Parks ..... P.O. Box 6683, Torrance, CA 90504 (213) 532-6066

Unitron Instruments Inc. ..... 175 Express St., Plainview, NY 11803 (516) 822-4601

TELESCOPE TUBES

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

Meade Instruments Corporation ..... 1675 Toronto Way, Costa Mesa, CA 92626 (714) 556-2291

W.R. Parks ..... P.O. Box 6683, Torrance, CA 90504 (213) 532-6066

TELESCOPES, COMPLETE

Celestron International ..... 2835 Columbia St., Torrance, CA 90503 (213) 328-9560

Coulter Optical Co. ..... 54121 Pinecrest Rd., Idyllwild, CA 92349 (714) 659-2991

Dodd Co. ..... 7795 W. Ridgewood Dr., Parma, OH 44129 (216) 886-2828

Edmund Scientific Company ..... 101 E. Gloucester Pike, Barrington, NJ 08007

Enterprise Optics ..... P.O. Box 413, Placentia, CA 92670 (714) 524-7520

Manitoba Museum Shop ..... 190 Rupert Ave., Winnipeg, Manitoba, R3B ON2, CANADA (204) 956-2830

Meade Instruments Corporation ..... 1675 Toronto Way, Costa Mesa, CA 92626 (714) 556-2291

Orion Telescope Center ..... P.O. Box 1158-T, Santa Cruz, CA 95061 (408) 476-8715

N. REMER OPTICS

Materials and supplies catering to Amateur Telescope Makers

REFRACTOR LENS KITS – 3", 4", and 6" clear aperture. Complete kits with instructions to make our award winning design.

MIRROR KITS – To 12½" Diameter. Pyrex blanks to 16".

ORTHOSCOPIC EYEPIECES – Coated 4, 6, 9, 12½, 18, and 25mm with 1¼" barrels.

COLOR FILTERS, STAR DIAGONALS
Lens Blanks, Abrasives, Polishes, Hex Tiles for low cost grinding tools, Telescope Tubing, Lens Cells, Etc.

Catalog and Price List Available
Please send 25 cents to:

N. REMER OPTICS
Box 306 R • Southampton, PA 18966
(215) 355-3086

TELESCOPE MAKERS' HARDWARE

1. DOBSONIAN BEARING KIT. Consists of six 3" dia, 1/16" thick Teflon discs (3 spare), 4 smaller "tabs" of Teflon for elevation bearings, and a 14" dia hard polished aluminum ring. The ring is taken from a computer disc mass storage unit, and is much smoother than Formica, which makes the Teflon last longer. Instructions.

Complete Kit.....$12 Ppd
Teflon only.....$9 Ppd

2. OPTICAL ALIGNMENT WASHERS. Made of stainless steel. A 1/4" bore, half spherical washer tilts in the cone-shaped depression machined into its mating washer. Use them in collimation devices and as pivots for floatation cells. Instructions.

6 Pair, $3. Each additional 3Pr, $1

Please remit by cashier's check or money order to:
RICHARD D. SHAFFER
228 E. Pentagon
Altadena, CA 91001

CA residents please add 6% Sales Tax.

The Dobsonian has reached Japan. The December issue of "Astronomy Guide" published a description of a 12" f/6 that knocks down for transport in a small car. Long boards have an "L" cross-section.

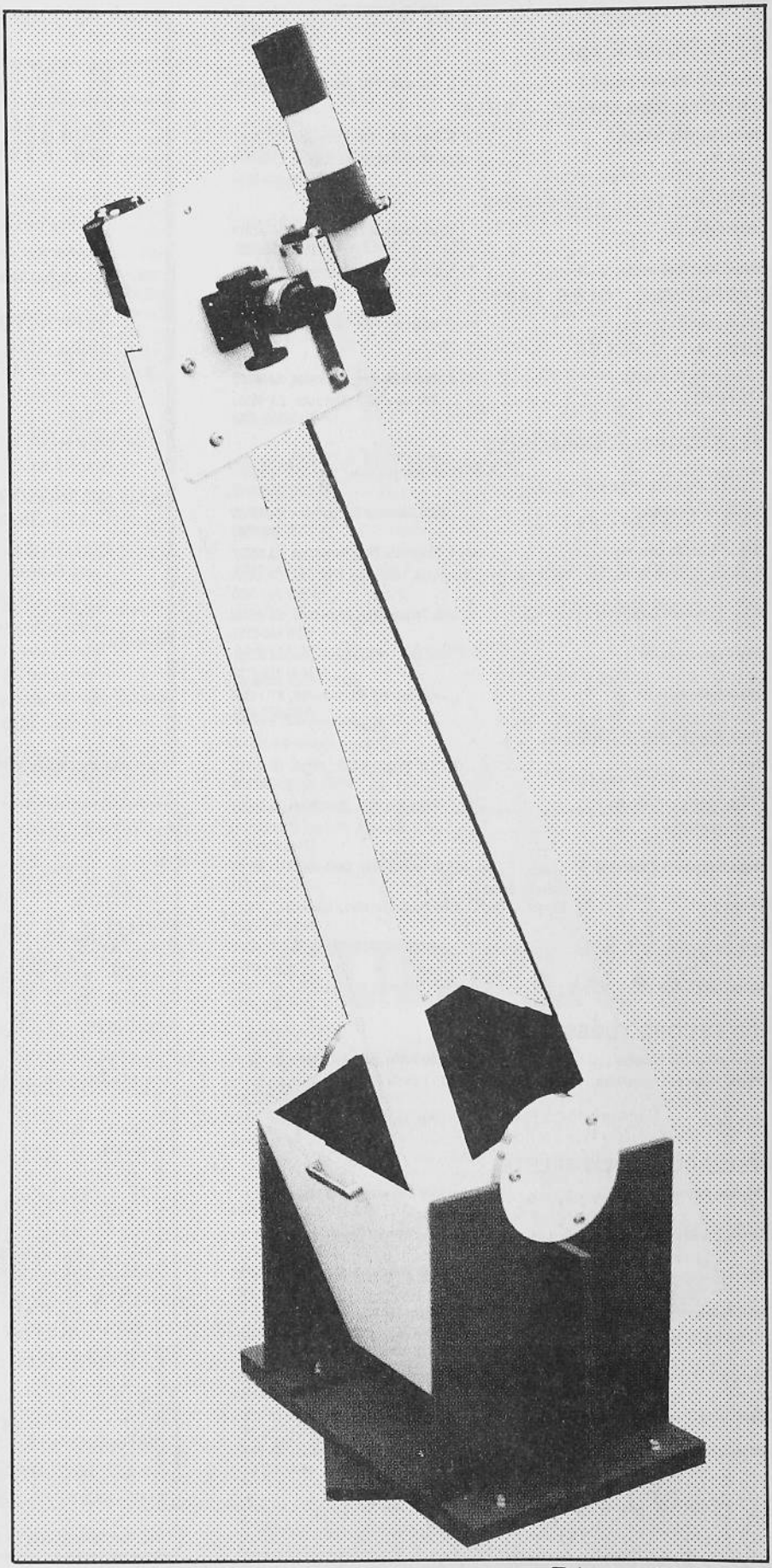
◀35

see through them, but each night so far has been totally cloud covered! It seems that the weather gets worse each year, leaving one to wonder whether solar observation (between the clouds, of course) might not be more sensible.

The Society's 10" telescope has so little use that the spiders have taken squatters rights. By the time you have decided to go out to the telescope, it has clouded over and started raining again! That is the advantage of having one's own telescope.

I must say that many amateurs over here are very jealous of the enormous range of telescopes and accessories that are available in the States. I suppose it is a matter of supply and demand, but your prices are but a fraction of ours, and we have a lower standard of living. It is very hard for a youngster to get a telescope over here unless he or she has a rich daddy. Even a four inch can cost 400 pounds for a simple Newtonian! A six inch refractor lens is over 600 pounds now.

And inflation makes a mockery of last year's price sheets. Just when you think you can afford something, its price doubles and they send your check back! It is no wonder there are so few telescope makers over here. There is really room for some enterprising person to start a small business making good quality telescopes at a price that Joe Public can really afford. I doubt I could make a go of it myself. Still, it's a thought.

C. Bolwell
29, Stirtingale Rd.
Kingsway,
Bath, Avon, England
BA2 2NF

— The answers to your questions are: 1) yes; 2) no, overseas is now $12; 3) no. Deal with us directly; 4) yes; 5) yes. We have reprinted back issues when they ran out.